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Results of the 1996 Firefighting and Damage Control Equipment Evaluation Tests (SCBA)

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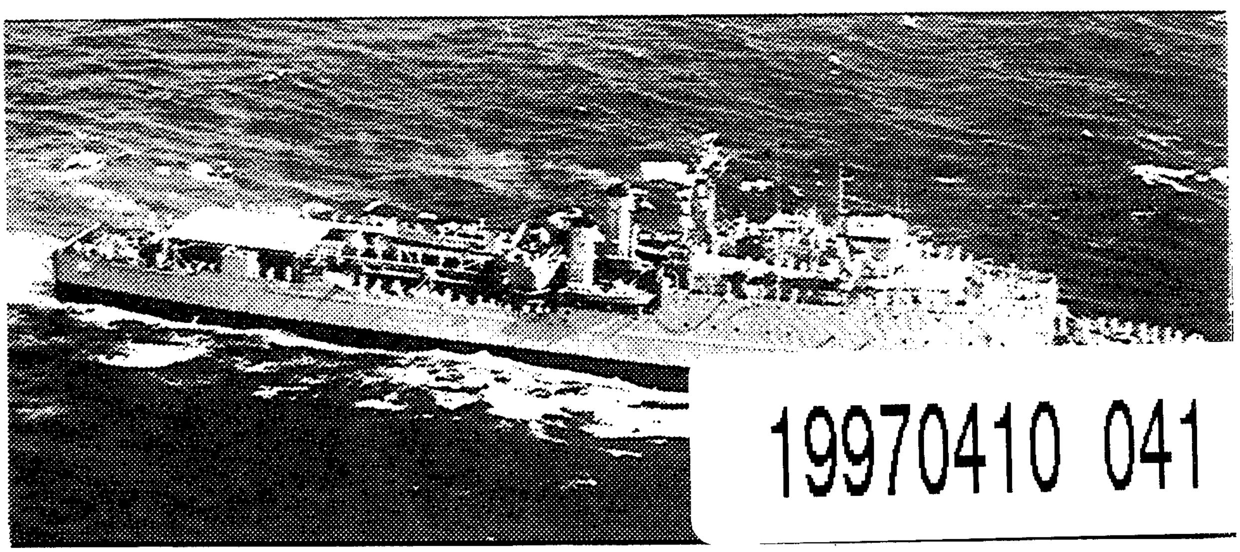

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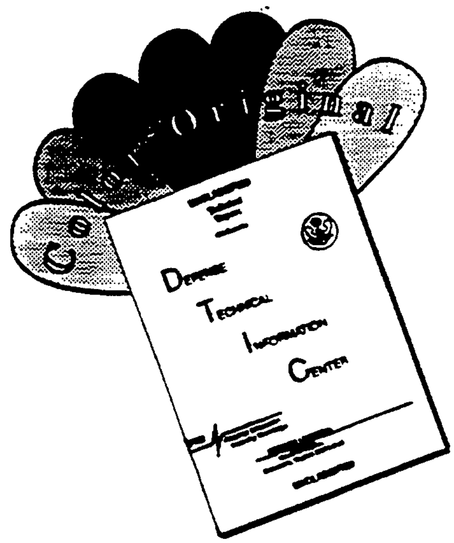

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A series of full-scale fire tests was conducted to evaluate the proposed self-contained breathing apparatus (SCBA) when used by firefighters to combat Class A fire scenarios. Based on the comments made by the test participants, it appeared that the majority of the participants preferred the SCBA over the OBA. Specifically, the participants preferred wearing the SCBA on the back, with a portion of the unit's weight being distributed to the hips, as opposed to wearing the OBA on the chest. The participants also stated that, due to the fact that the SCBA was on their backs, the SCBA allowed for greater mobility than the OBA. During the test series, several of the participants experienced problems with their mask-mounted voice amplifiers, such as feedback and inoperable amplifiers. Due to the size of the firefighting gloves, the bypass relief valve and the regulator release tabs on the SCBA masks were extremely difficult for the firefighters to manipulate while wearing gloves.

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Results of the 1996 Firefighting and Damage Control Equipment Evaluation Tests (SCBA)

1.0 INTRODUCTION

Fleet evaluation tests are conducted on the ex-USS SHADWELL to evaluate new tactics, procedures, doctrine, and equipment which are being introduced to the Fleet [1]. In the past, new concepts related to smoke management, CBR, and firefighting attack have been developed [2-8]. Integration of repair locker teams has been an important component in these studies. As the Fleet evaluation test concept has evolved, ancillary studies have been "piggy-backed" onto the primary test series. Ancillary studies have included physiological evaluations of test participants [9], and evaluation of improved damage control communication and management systems [10].

The FY96 firefighting and damage control test series was developed to provide different fire challenges with which new damage control equipment and concepts could be evaluated. One area of particular interest in FY96 was the use of the self-contained breathing apparatus (SCBA). The SCBA has been approved as a replacement for the Navy Oxygen Breathing Apparatus (OBA). The results of the SCBA evaluations will be useful for developing work/rest cycles, operational guidance and procedures, and equipment support requirements. This information will in turn be used to assist with the introduction of these units into the Fleet.

For the purpose of this evaluation, it was assumed that the SCBA would replace the OBA. NFPA Standard 1981 [11] contains the requirements for design, performance, testing, and certification of open-circuit SCBA for use in firefighting environments. These units are required to be NIOSH/MSHA certified in accordance with reference [12]. SCBA units meeting these requirements and performance requirements established by NAVSEA, are commercially available from a number of different manufacturers. Units manufactured by Mine Safety Appliances Co. (MSA) were used for these tests. Composite SCBA cylinders are typically available in nominal sizes of 30, 45, and 60 minutes. However, as capacity increases, the size and weight also increase. This in turn increases the physical exertion of the person wearing the apparatus. The impact of the increased weight of the larger capacity units needs to be judged with respect to the longer operation time available from the increased air capacity. To quantify these effects, composite cylinders of all three sizes were evaluated, with emphasis on the 30 and 45 minute units.

SCBA units, manufactured by Drager, were field-evaluated on the USS TORTUGA (LSD 46). This evaluation involved the use of SCBA units in simulated fire and damage control evolutions. Preliminary results indicated that a 30 minute cylinder was acceptable for short duration scenarios, e.g., scenarios which might be associated with Repair 2 (forward repair). The 45 minute cylinder (which reportedly provided about 30 minutes of air under working conditions) was considered more advantageous for a protracted attack, e.g., those associated with Repair 5

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(Propulsion Plant) and Repair 3. The 60 minute cylinder was considered too heavy for situations involving any high degree of physical effort. It may, however, be appropriate for long duration, low physical exertion situations. It has been suggested for use by the On-Scene Leader.

The objectives of the SCBA evaluations were to

1. Determine the "learning curve" for fleet personnel to understand the use of the new equipment.

2. Evaluate the performance of the SCBA compared to the OBA to identify any changes in doctrine/procedures.

3. Identify optimum management strategies for controlling SCBA use.

4. Provide recommendations for standard guidance and procedures for anticipated changes to NSTM and training manuals.

5. Provide experience to fleet personnel by using a workshop as a means to introduce the SCBA to the Fleet and obtain Fleet feedback based on shipboard fire experience.

During this test series several pieces of damage control equipment and clothing were evaluated. Included in the clothing evaluations were different types of gloves and a new firefighting ensemble design. The ancillary equipment evaluations included the EZ Pup firehose nozzle handling device and the Fire Drill-2. This report includes a brief description of the results of the equipment evaluations. The results of the clothing evaluations will be prepared separately by NCTRF.

2.0 APPROACH

Four fire threats were used to evaluate the performance of the SCBA. A total of 16 fleet personnel participated in the evaluation. Personnel were assigned to the Repair Party as shown in Table 1. The primary functions included the attack team, boundarymen, and investigators. SCBAs were initially assigned based on the results of the USS TORTUGA evaluation (e.g., attack team used a 45 minute cylinder). As testing progressed, the allocations were modified based on the results of the tests.

Familiarization and testing were accomplished over a one week time period, 12-16 August, 1996. The fire scenarios were refined prior to the participants coming aboard the ex-USS SHADWELL (Tests scba_01 and scba_02). On the first day of the workshop, participants were familiarized with the SCBA, using dry runs (i.e., no fire). On the second day, a horizontal attack was performed on a Class A flashover scenario (scenario #1). On the third day, a third

deck fire, requiring a vertical attack, was used to challenge the participants (scenario #2). On the fourth day, scenario #2 was repeated in low visibility conditions (scenario #3). On the final day, a conflagration combining scenarios #1 and #2 was used to challenge the participants. Table 2 summarizes the threats and scenarios associated with each test.

Table 1. Repair Party Organization for SCBA Evaluations

Number of Personnel	Function	Dress
1	Scene Leader	Firefighters ensemble
1	Attack Team Leader	Firefighters ensemble
1	Nozzleman	Firefighters ensemble
2	Hoseman	Firefighters ensemble
1	Plugman	Firefighters ensemble
2	Investigator	Fire retardant coverall
4	Boundarymen	Fire retardant coverall
4	Access/overhaul	Firefighters ensemble

Table 2. Test Matrix

Test	Threat	Scenario
scba_03	#1 - 2nd Deck Flashover	Horizontal fog attack
scba_04	#2 - 3rd Deck Class A	Vertical attack
scba_05	#3 - 3rd Deck Class A with low visibility	Vertical attack
scba_06	#4 - Combination of #1 and #2	Conflagration

3.0 TEST SETUP

3.1 General Setup

Testing was conducted in the forward area of the ex-USS SHADWELL, on the first (main), second, and third decks between FR 9 and FR 22 (Figs. 1-3). The actual test areas were on the second deck, between FR 15 and FR 22 (Fig. 4) in the spaces designated as Storage and GSK (2-15-2-A and 2-15-1-Q) and on the third deck between FR 15 and FR 22 (Fig. 5) in the space designated as Berthing 2 (3-16-0-L). The second deck test area was divided into two

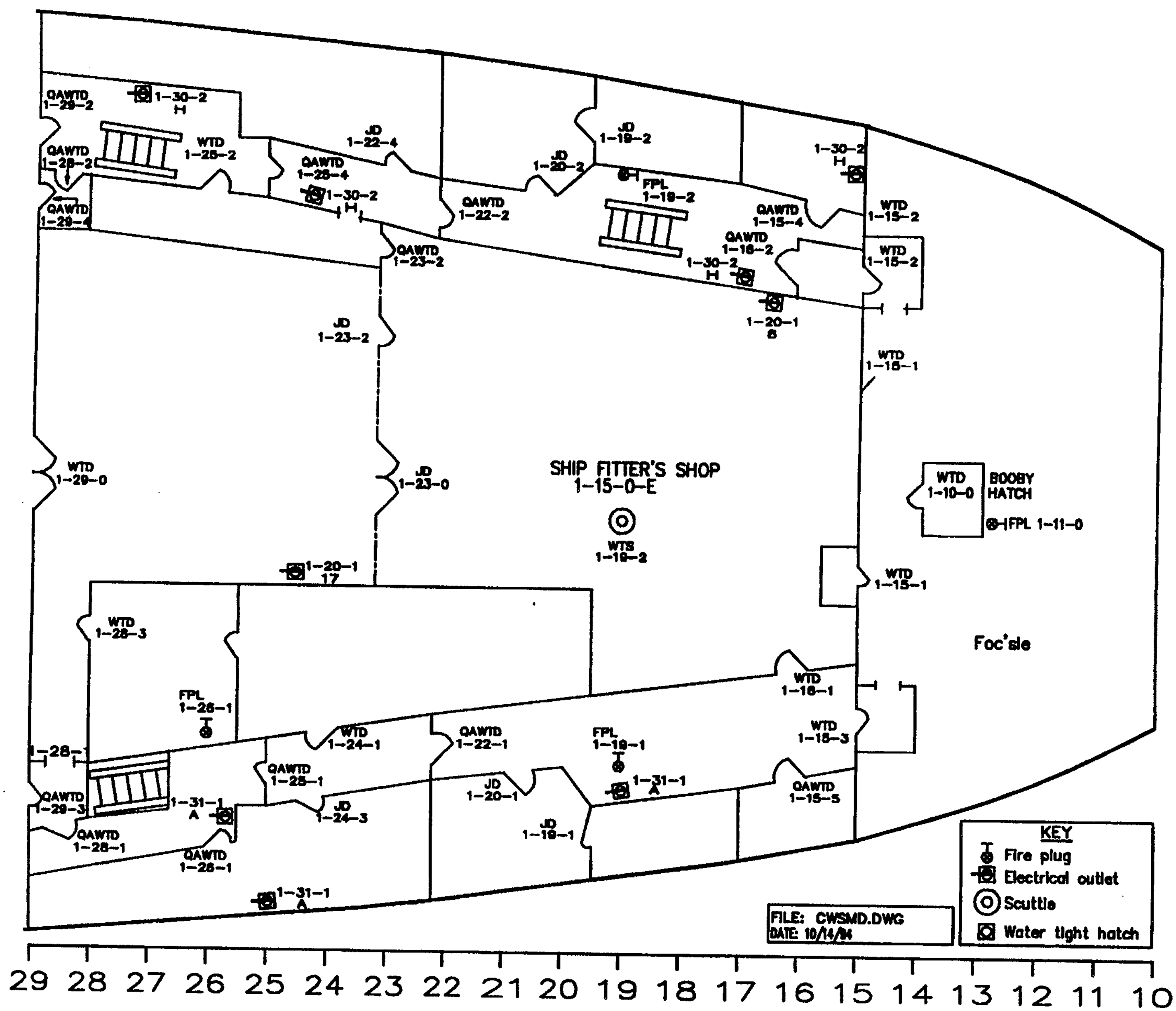


Fig. 1 – First (Main) deck plan view, FR 10–29

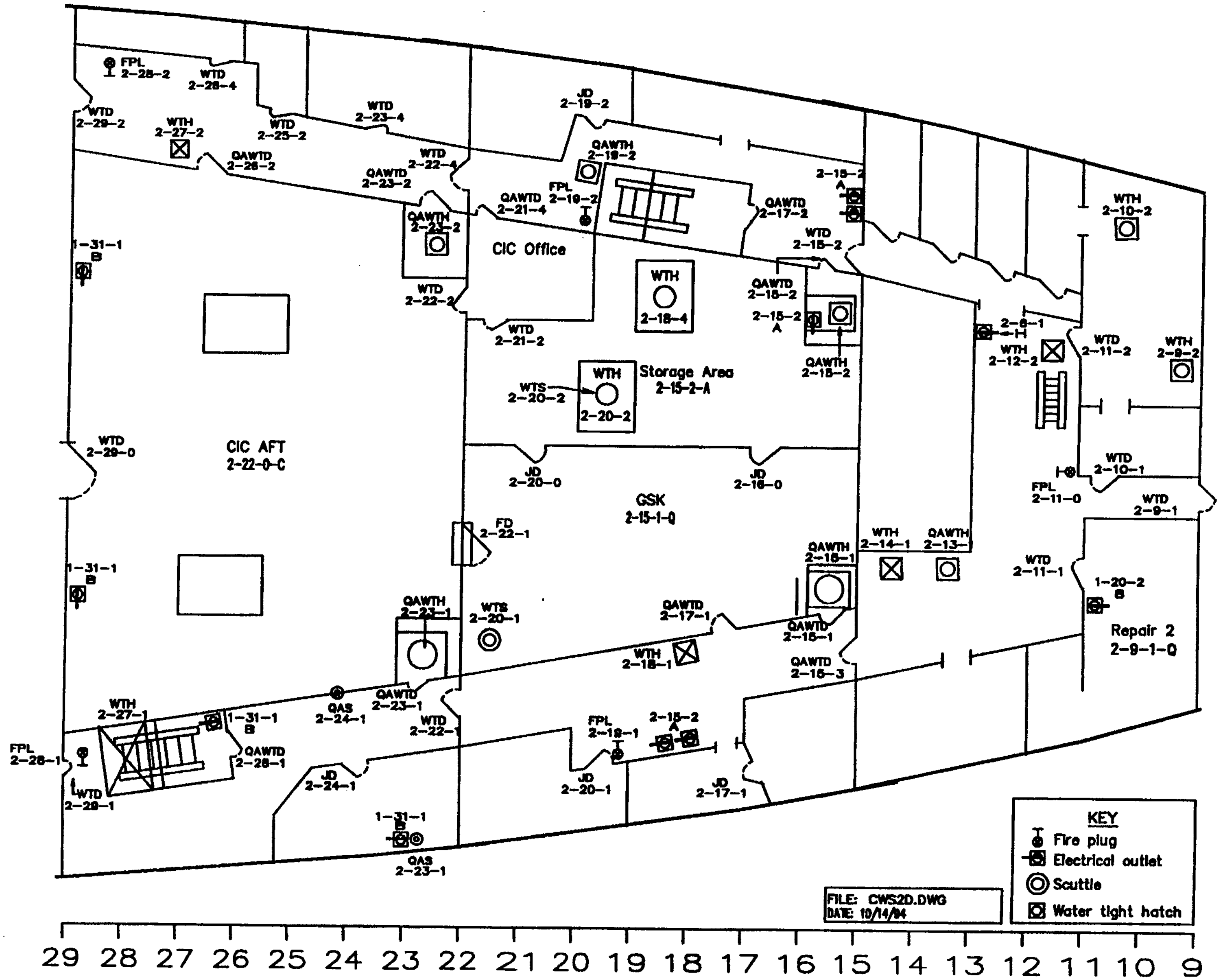


Fig. 2 – Second deck plan view, FR 9–29

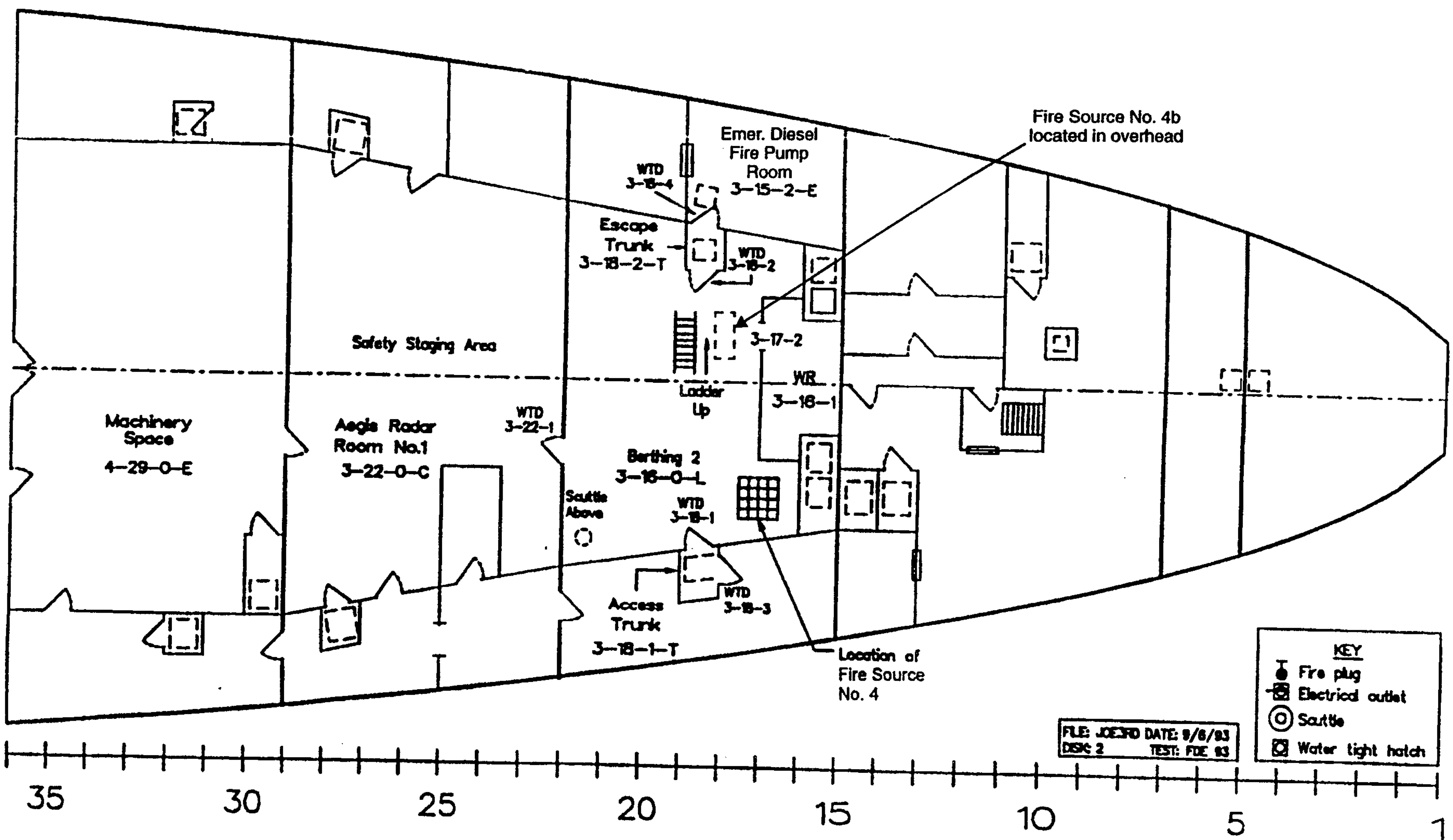


Fig. 3 — Third deck plan view

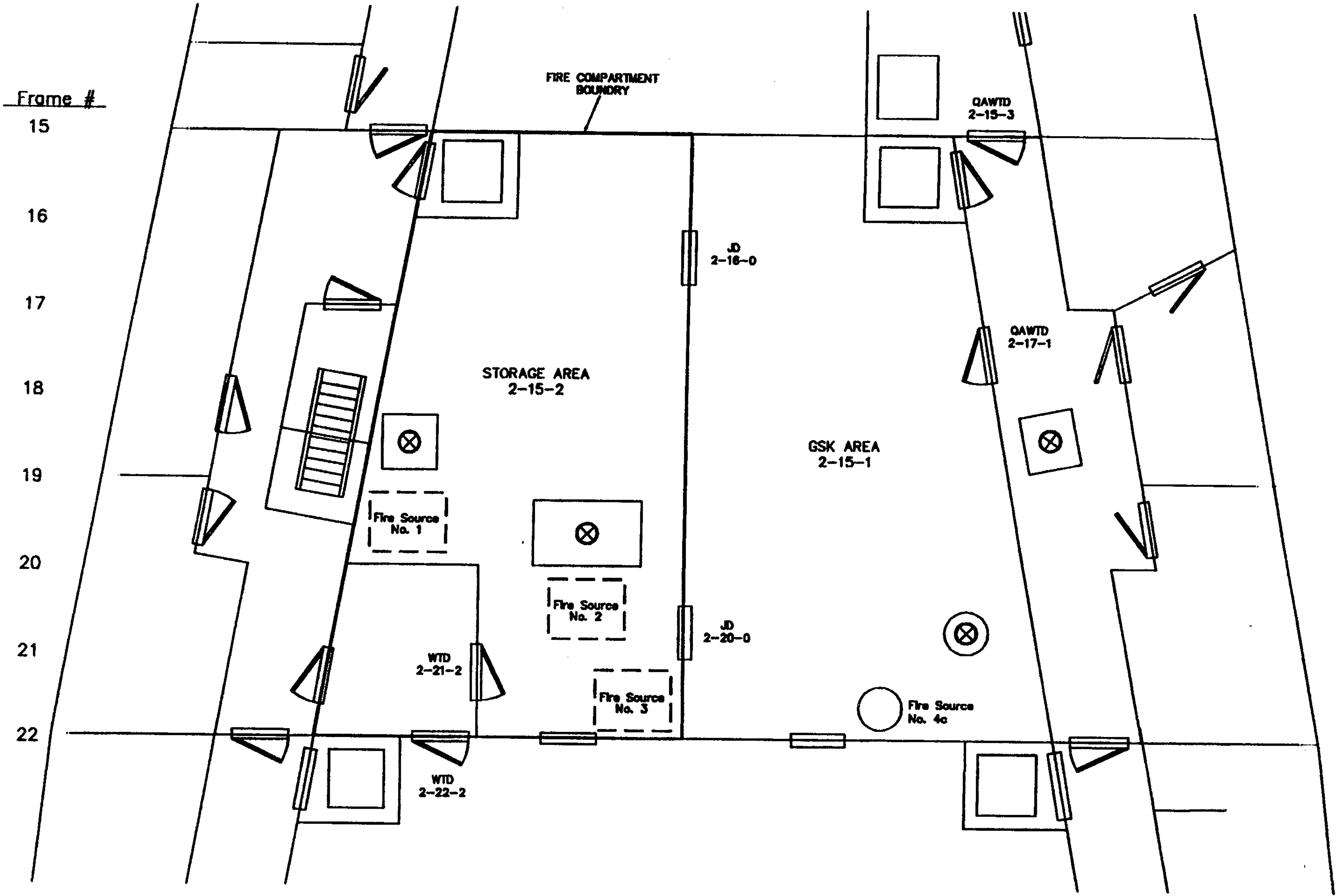


Fig. 4 – Second deck test area plan view (FR 15–23)

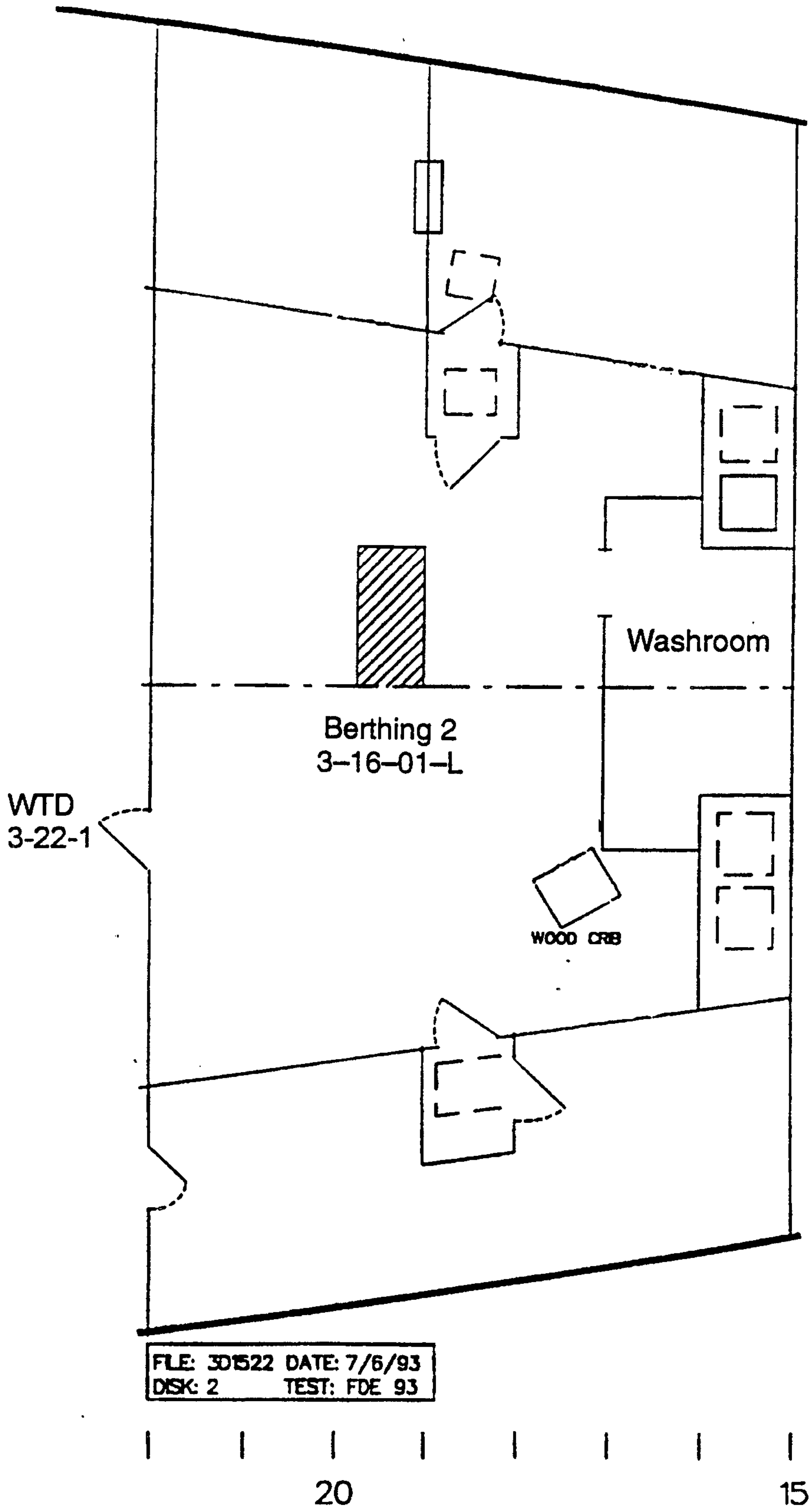


Fig 5 — Third deck fire source layout, plan view (FR 15-22)

compartments by a bulkhead which runs down the centerline of the ship from(FR 15-22). The compartment to port was designated as the Storage area and the compartment to starboard was designated as GSK. The centerline bulkhead had two joiner doors, one forward at FR 16 and the other aft at FR 20, which provided access between the two compartments.

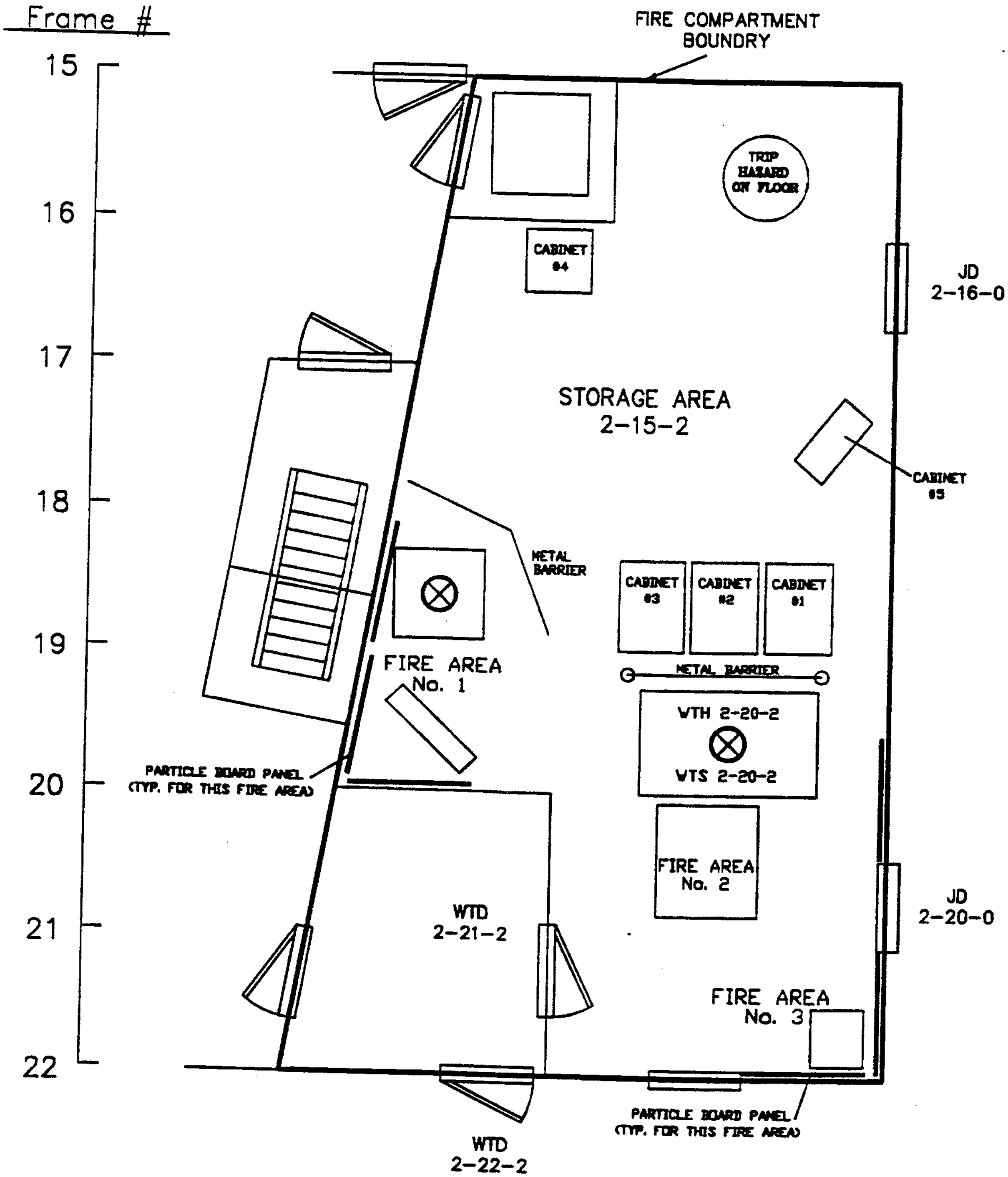
The second deck fire area was in the aft portion of the Storage compartment (Fig. 4). Fires in this area consisted of multiple fire source, Class A growing/steady state fires as described in references [6] and [7]. To further increase the difficulty of the second deck firefighting evolutions, each of the fire sources was obstructed by metal panels, lockers, and cabinets (Fig. 6). This forced the attack team to advance well into the fire compartment before being able to initiate a direct attack on the seat of the fire. Access to the fire area was via the starboard passageway through the watertight door (QAWTD 2-17-1) into GSK, and then through the forward joiner door (JD 2-16-0) into the Storage compartment. Repair 2 (2-9-1-Q) was used as the staging area for the attack team. The foc's'le area forward of the shipfitters shop (1-15-0-E) on the main deck and CIC Aft (2-22-2) on the second deck served as emergency escape and muster areas for personnel on the second deck.

The third deck fire was located in the starboard corner of Berthing 2, adjacent to the exhaust shaft for exhaust fan E1-15-1. This fire was unobstructed, allowing the attack team to perform a direct attack from the base of the ladder after performing an indirect attack from GSK and entering vertically from the second deck via WTH 2-20-2. This fire scenario was similar to that used in tests described in reference [5]. Again, Repair 2 (2-9-1-Q) was used as the staging area for the attack team. Access to the fire area was via the starboard passageway through the watertight door (QAWTD 2-17-1) into GSK, through the forward joiner door (JD 2-16-0) into the Storage compartment, aft to watertight hatch WTH 2-20-2, and then down the ladder into Berthing 2. The well deck area aft of the DDG 51 machinery space, the DC passage on the starboard side of the fire compartment and the foc's'le area forward of the shipfitters shop (1-15-0-E) on the main deck served as emergency escape and muster areas for personnel on the third deck.

In Scenario #3, the third deck fire scenario was modified to create a low visibility condition. To create this condition, the ventilation configuration was modified slightly and a diesel pool fire was ignited in GSK. The fire scenarios are discussed in more detail later in this report.

3.2 Ventilation System

Ventilation air used for these tests was supplied from the ship ventilation system, TPSS (Total Protection Supply System) and TPES (Total Protection Exhaust System) [13]. The supply system outlet for the second deck test area was located near the aft bulkhead of the Storage compartment in the overhead. The second deck exhaust inlet was located near the center of the Storage compartment in the overhead. The supply system outlet for the third deck test area was located at FR 21 in the overhead.



Cabinet Sizes (cm (in))

Cabinet #1 61x46x163 cm (24x18x64 in)
Cabinet #2 66x43x178 cm (26x17x70 in)
Cabinet #3 (66x43x175 cm (26x17x69 in)
Cabinet #4 (56x25x94 cm (22x10x37 in)
Cabinet #5 (56x51x94 cm (22x20x37 in)

Fig. 6 – Second deck fire source and obstruction layout plan view (FR 15–22)

The setup described in the following sections is for the initial conditions. After the Repair Party was called away to the fire, some of these conditions changed as a result of actions taken by the Repair Team. A detailed description of the actions taken during each test is given later.

3.2.1 Ventilation Configuration for Scenario #1

In scenario #1, the TPSS and TPES were both operational during the entire test. Additional fresh air was supplied to the fire compartment from Aft CIC via the CIC Office. This was accomplished by leaving WTD 2-20-2 fully open and throttling the air flow with WTD 2-22-2. The additional fresh air was only supplied during the initial preburn. Prior to the attack team entering the fire compartment WTD 2-22-2 was closed. The F-stops to both exhaust system shafts at FR 15 (port and starboard) were left open to provide a natural ventilation path from the test area. Both of these shafts discharge to weather at the 02 level. The fans on these systems were not activated during the firefighting evolution. To prevent air flow into the port passageway WTD 2-26-2, WTD 2-22-6, and WTD 2-15-2 were closed. To prevent air flow into the starboard passageway WTD 2-17-1 and WTD 2-16-1 were closed. To prevent air flow into Aft CIC the joiner door, JD 2-22-1, was closed. However, since this door, as well as WTD 2-17-1, were used by the safety team to move through the test area, they were opened and closed several times during the test. The joiner doors (2-16-0 and 2-20-0) between GSK and the Storage area were closed. The joiner door at FR 16 was used by the safety team to access the Storage area to observe the fire during the preburn. All of the second deck accesses to the main and third decks, between FR 15 and FR 22 were secured. This included WTH 2-20-2, WTD 2-25-1, WTD 2-17-2, and WTS 2-21-1. The two water-tight doors, WTD 2-25-1 and WTD 2-17-2 isolated stairwells in the starboard and port passageways, respectively. The boundaries of the test area were secured by closing WTD 2-29-1, WTD 2-29-2, WTD 2-15-1, and WTD 2-15-4.

3.2.2 Ventilation Configuration for Scenario #2

For scenario #2, the TPSS and TPES were operational for the entire test. Additional fresh air was supplied to the fire compartment through WTD 3-22-1 and through a 0.3 m (1 ft) diameter deck drain open to weather on the starboard side of the ship. To ventilate Berthing 2, two water-tight scuttles (WTS 2-20-2 and WTS 2-21-1) were left open during the preburn. Prior to the attack team entering GSK, the two scuttles and WTD 3-22-1 were closed. On the second deck both F-stops were left open for the entire test. To prevent the spread of smoke into the port passageway, WTD 2-26-2, WTD 2-22-6, and WTD 2-15-2 were closed. To prevent the flow of smoke into the starboard passageway, WTD 2-17-1 and WTD 2-16-1 were closed. To prevent smoke spread into Aft CIC, JD 2-22-1 was closed. As in scenario #1, JD 2-22-1 and WTD 2-17-1 were used by the safety team to move through the test area. The joiner door at FR 16 (JD 2-16-0), separating GSK and Storage, was open during the preburn and closed prior to the initiation of the attack. All of the vertical accesses connecting the main and second decks were closed, with the exception of the booby hatch at FR 11 on the foc's'le. This door was used by the Repair Party to enter the test area. The boundaries of the test area were secured by closing WTD 2-29-1, WTD 2-29-2, WTD 2-15-1, and WTD 2-15-4.

3.2.3 Ventilation Configuration for scenario #3

The configuration for scenario #3 was designed to allow smoke to spread throughout the test area. The TPSS and TPES were operational during the entire test. Both of the FR 15 F-stops were open during this test. Additional fresh air was supplied to the fire compartment through WTD 3-22-1 and through a 0.3 m (1 ft) diameter deck drain open to weather on the starboard side of the ship. To ventilate Berthing 2, two water-tight scuttles (WTS 2-20-2 and WTS 2-21-1) were left open during the preburn. Prior to the attack team entering GSK, the two scuttles and WTD 3-22-1 were closed. To allow the smoke to spread into the port passageway, WTD 2-26-2, WTD 2-20-2, WTD 2-22-4, and WTD 2-15-2 were open during this test. However, due to the temperature of the air in the CIC Office, the water-tight door (WTD 2-21-2), which opened directly into the passageway, remained closed. To allow smoke movement into the starboard passageway, WTD 2-17-1 and WTD 2-16-1 were left open during the test. WTD 2-15-2 and WTD 2-16-1 opened into the FR 15 exhaust trunks. To prevent air flow between GSK and Aft CIC, JD 2-22-1 was closed. As in scenario #1, this door was used by the safety team to move through the test area. All of the vertical accesses connecting the main and second decks were closed, with the exception of the booby hatch at FR 11 on the foc's'le. The boundaries of the test area were secured by closing WTD 2-29-1, WTD 2-29-2, WTD 2-15-1, and WTD 2-15-4.

3.2.4 Ventilation Configuration for Scenario #4

The TPSS and TPES were operational during the entire test. Both of the FR 15 F-stops were open during this test. Additional fresh air was supplied to the 3rd deck fire compartment through WTD 3-22-1 and through a 0.3 m (1 ft) diameter deck drain open to weather on the starboard side of the ship. To ventilate Berthing 2, two water-tight scuttles (WTS 2-20-2 and WTS 2-21-1) were left open during the preburn. Prior to the attack team entering GSK, WTS 2-21-1 and WTD 3-22-1 were closed. Due to the locations of the fires in the Storage area, WTS 2-20-2 was not closed prior to the attack team entering GSK. Additional fresh air was supplied to the second deck fire compartment from Aft CIC via the CIC Office. This was accomplished by leaving WTD 2-20-2 fully open and throttling the air flow with WTD 2-22-2. The additional fresh air was only supplied during the initial preburn. Prior to the attack team entering the fire compartment WTD 2-22-2 was closed. WTD 2-26-2 and WTD 2-17-1 were left open, to allow smoke to spread into the port and starboard passageways, respectively. To prevent air flow between GSK and Aft CIC, JD 2-22-1 was closed. The joiner doors (2-16-0 and 2-20-0) between GSK and the Storage area were also closed. The joiner door at FR 16 was used by the safety team to access the Storage area to observe the fire during the preburn. All of the vertical accesses connecting the main and second decks were closed, with the exception of the booby hatch at FR 11 on the foc's'le. The boundaries of the test area were secured by closing WTD 2-29-1, WTD 2-29-2, WTD 2-15-1, and WTD 2-15-4.

3.3 Fuel Load

3.3.1 Fuel Load for Scenario #1

The fire threat for this scenario consisted of three wood cribs and six particle board panels. The wood cribs were initiated by n-heptane pool fires. The fuel load was distributed as shown in Fig. 6. Details of the wood crib construction and fuel load arrangement are given in Table 3. The wood cribs (Figs. 7, 8, and 9) were constructed with red oak sticks cut to nominal sizes of 50 x 50 x 1200 mm (2 x 2 x 48 in.), 50 x 50 x 600 mm (2 x 2 x 24 in.), and 50 x 50 x 300 mm (2 x 2 x 12 in.) as described in Table 3. The cribs were assembled in place on metal support stands 0.58 m (23 in.) above the deck. A metal pan, to hold the initiating fuel, was placed beneath each of the metal stands. The amount of fuel used for preburn varied by location as shown in Table 3. Particle board panels measuring 1.2 m x 2.4 m x 1.3 mm thick (4.0 ft x 8.0 ft x 0.5 in. thick) were installed vertically against the bulkheads of the compartment adjacent to wood crib locations No. 1 and No. 3 (Figs. 7 and 9, respectively). The crib support stands were used to hold the panels in place against the bulkhead.

To further simulate a storage area fire, and to make the attack more challenging, metal panels and lockers (Fig. 7 and 10) were located around the compartment such that they obstructed direct access to the fire source. The exact locations of the obstructions are shown in Fig. 6.

3.3.2 Fuel Load for Scenario #2

The fire threat for this scenario consisted of two wood cribs located in the third deck fire compartment, designated as Berthing 2. The wood cribs (Figs. 11 and 12) were constructed with red oak sticks cut to nominal sizes 50 x 50 x 1200 mm (2 x 2 x 48 in.) and 50 x 50 x 300 mm (2 x 2 x 12 in.). Details of the wood crib construction are given in Table 3. One of the wood cribs (No. 4) was initiated by an n-heptane pool fire, the other crib (No. 4b), located in the overhead, was not manually ignited. It was intended that this crib be sympathetically ignited from the heat in the overhead from crib source #4. A metal pan holding the initiating fuel was placed beneath the metal stand supporting crib No. 4. Two gallons of n-heptane were used to preburn the wood crib. There were no particle board panels used in this scenario.

3.3.3 Fuel Load for Scenario #3

The fire threat for this scenario was the same as that for scenario #2 with one addition. To create the low visibility condition desired, a small diesel pool fire was placed in GSK. The 0.6 m (2.0 ft) diameter pan was filled with 7.6 liters (2.0 gal) of diesel and 1.9 liters (0.5 gal) of n-heptane. The pan was located at FR 22 in GSK, as shown in Fig. 4 and Fig. 13. There were no particle board panels used in this scenario.

Table 3. Summary of Fuel Load for Each Fire Scenario

Fire Scenario	Fire Source Location	Wood Crib Construction	Initiating Fuel	Particle Board Panels
1	1	15 rows, alternating pattern; - Bottom row, 3-1.2 m (48 in.) spaced 25 mm (1 in.) apart - Next row, 2-0.3 m (12 in.) spaced 0.6 m (24 in.) apart	3.8 liters (1.0 gal) n-Heptane in a 0.6 m (24 in.) diameter pan	3 total: - 2 against port BH - 1 against fwd CIC Office BH
	2	10 rows of 10 sticks each, all 1.2 m (48 in.) long spaced 25 to 50 mm (1 to 2 in.) apart	11.4 liters (3.0 gal) n-Heptane in a 0.9 m x 0.9 m (36 in. x 36 in.) square pan	None
	3	8 rows of 8 sticks each, all 0.6 m (24 in.) long spaced 25 mm (1.0 in.) apart	7.6 liters (2.0 gal) n-Heptane in a 0.6 m (24 in.) diameter pan	3 total: - 2 against centerline BH - 1 against aft BH
2	4	13 rows of 10 sticks each, all 1.2 m (48 in.) long, spaced 25 to 50 mm (1 to 2 in.) apart	7.6 liters (2.0 gal) n-Heptane in a 0.6 m (24 in.) diameter pan	None
	4b	12 - 1.2 m (48 in.) long sticks of wood arranged in 3 rows of 4 separated by rows of 3 - 0.3 m (12 in.) sticks, located in overhead	None	None
3	4	13 rows of 10 sticks each, all 1.2 m (48 in.) long, spaced 25 to 50 mm (1 to 2 in.) apart	7.6 liters (2.0 gal) n-Heptane in a 0.6 m (24 in.) diameter pan	None
	4b	12 - 1.2 m (48 in.) long sticks of wood arranged in 3 rows of 4 separated by rows of 3 - 0.3 m (12 in.) sticks, located in overhead	None	None

Table 3. (cont.)

Fire Scenario	Fire Source Location	Wood Crib Construction	Initiating Fuel	Particle Board Panels
4	1	15 rows, alternating pattern; - Bottom row, 3-1.2 m (48 in.) spaced 25 mm (1 in.) apart - Next row, 2-0.3 m (12 in.) spaced 0.6 m (24 in.) apart	3.8 liters (1.0 gal) n-Heptane in a 0.6 m (24 in.) diameter pan	None
	2	10 rows of 10 sticks each, all 1.2 m (48 in.) long spaced 25 to 50 mm (1 to 2 in.) apart	11.4 liters (3.0 gal) n-Heptane in a 0.9 m x 0.9 m (36 in. x 36 in.) square pan	None
	3	8 rows of 8 sticks each, all 0.6 m (24 in.) long spaced 25 mm (1.0 in.) apart	7.6 liters (2.0 gal) n-Heptane in a 0.6 m (24 in.) diameter pan	3 total: - 2 against centerline BH - 1 against aft BH
	4	13 rows of 10 sticks each, all 1.2 m (48 in.) long, spaced 25 to 50 mm (1 to 2 in.) apart	7.6 liters (2.0 gal) n-Heptane in a 0.6 m (24 in.) diameter pan	None
	4b	12 - 1.2 m (48 in.) long sticks of wood arranged in 3 rows of 4 separated by rows of 3 - 0.3 m (12 in.) sticks, located in overhead	None	None

Fig. 7 – Fire source No. 1 (viewed through obstruction)

Fig. 8 – Fire source No. 2 (viewed from WTD 2-21-2)

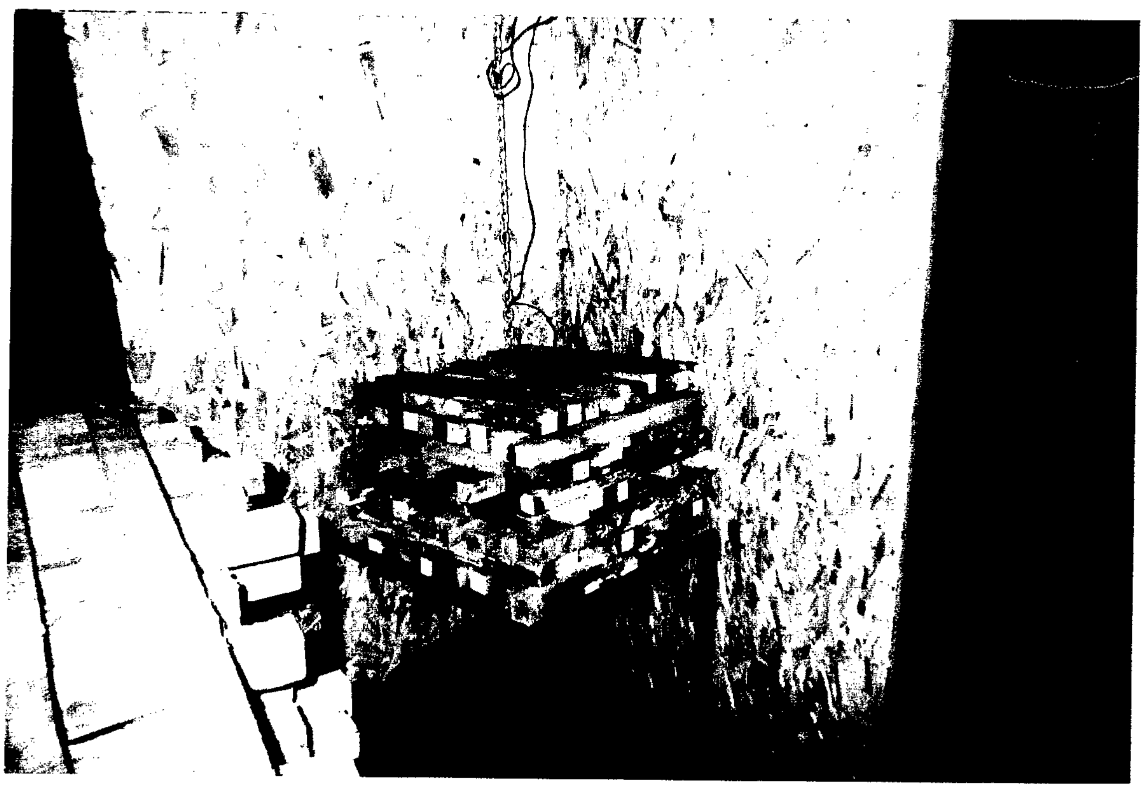


Fig. 9 – Fire source No. 3 (viewed from WTD 2-21-2)

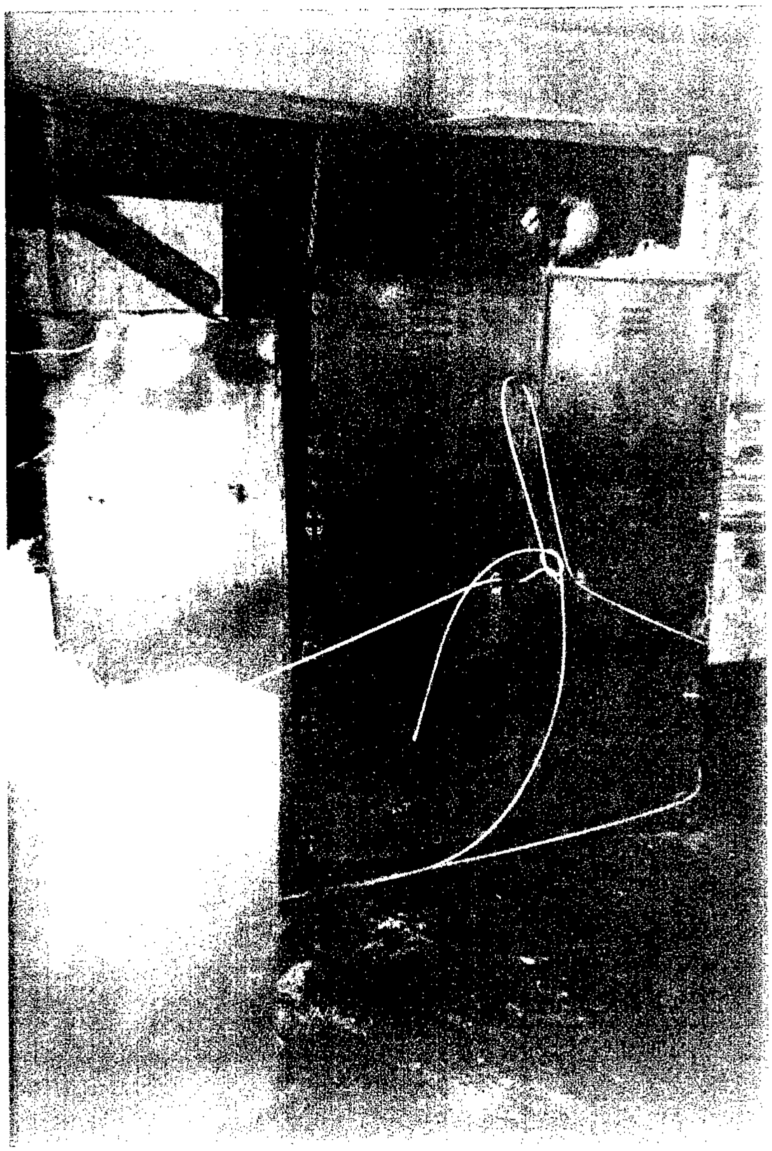


Fig. 10 - Metal lockers located in front of fire source No. 2 (viewed from JD 2-16-0)

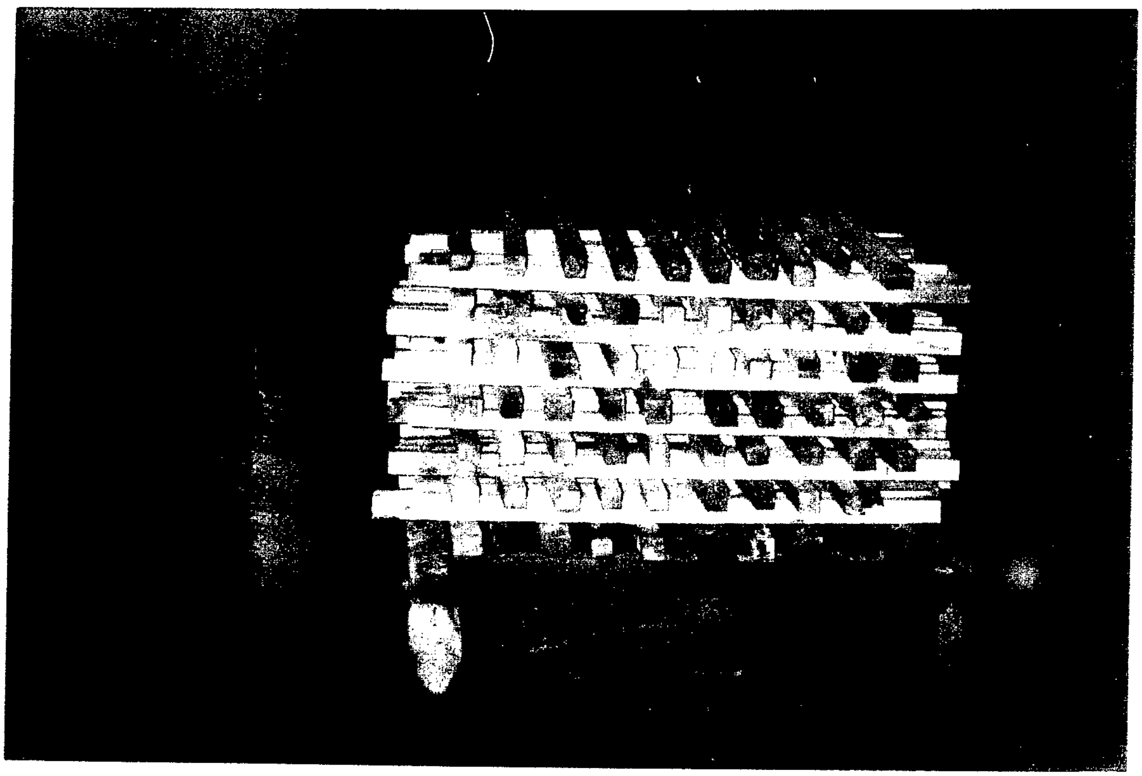


Fig. 11 — Fire source no. 4 (viewed from WTD 3-22-1)

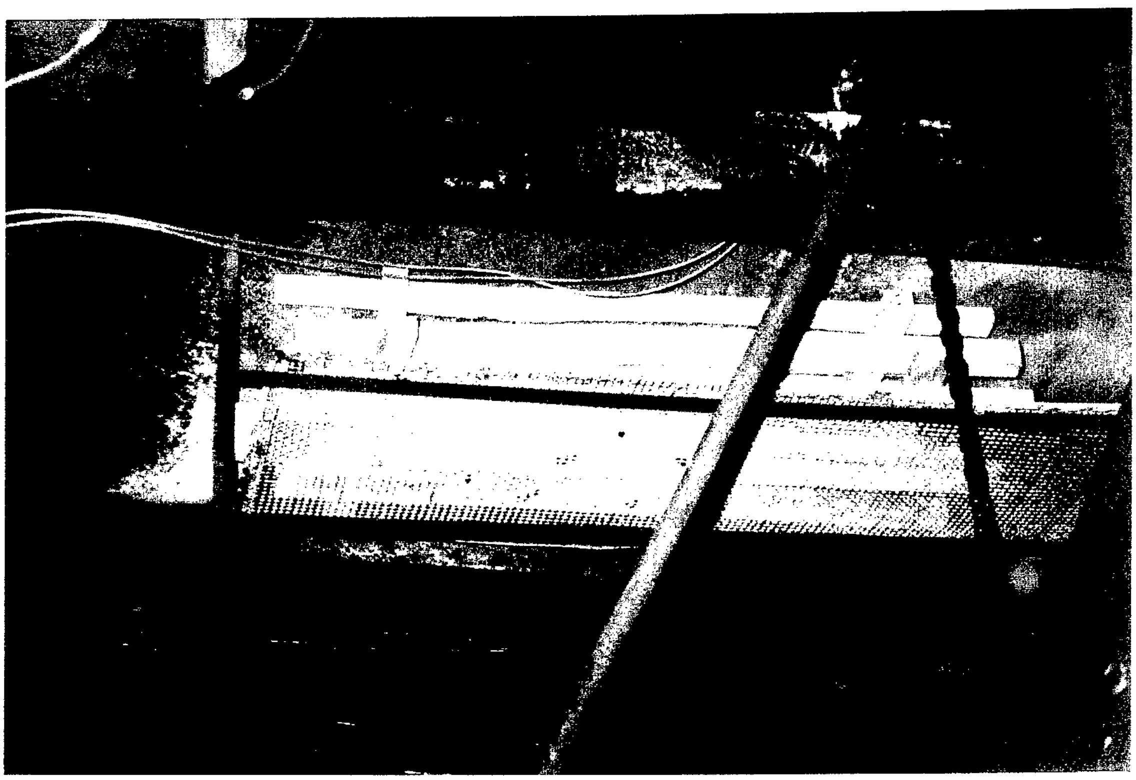


Fig. 12 — Fire source No. 4b in overhead of Berthing 2

Fig. 13 — Fire source No. 4c used in Scenario #3
(Test SCBA-05)

3.3.4 Fuel Load for Scenario #4

The fire threat for this scenario was a combination of the threats used in scenarios #1 and #2, resulting in a total of 5 wood cribs and six particle board panels. Details of the wood crib construction and fuel load distribution are given in Table 3.

3.4 Instrumentation

Instrumentation for these tests included the following:

1. Thermocouples to measure air temperatures in the overhead and at various elevations;

2. Thermocouples to measure the flame temperatures within and immediately above each of the wood cribs;

3. Thermocouples to measure the surface temperature of bulkheads and decks;

4. Calorimeters and radiometers to measure the total and radiant heat flux;

5. Gas analyzers for measurement of oxygen, carbon monoxide, and carbon dioxide concentrations;

6. Ultrasonic flow meters to measure water flow rates and cumulative water volume; and

7. Optical density meters to measure smoke obscuration.

Fig. 14 shows the location of all instrumentation located in the second deck fire compartment and adjacent second deck compartments. Fig. 15 shows the location of all of the instrumentation located in the third deck fire compartment and adjacent third deck compartments. A symbol legend for these drawings is provided in Table 4. Both audio and visual images were also recorded as well as stationary IR images.

3.4.1 Thermocouples

Type K, inconel-sheathed thermocouples, 3.2 mm (0.13 in.) and 1.6 mm (0.06 in.) outside diameter, were used to measure air, overhead, deck and bulkhead surface, and crib flame temperatures.

Air temperatures were measured in GSK by two vertical thermocouple strings mounted on stands located at FR 22 on the port side of the compartment (2-22-0) and FR 21 on the starboard side of the compartment (2-21-1). The air temperatures in Storage were measured

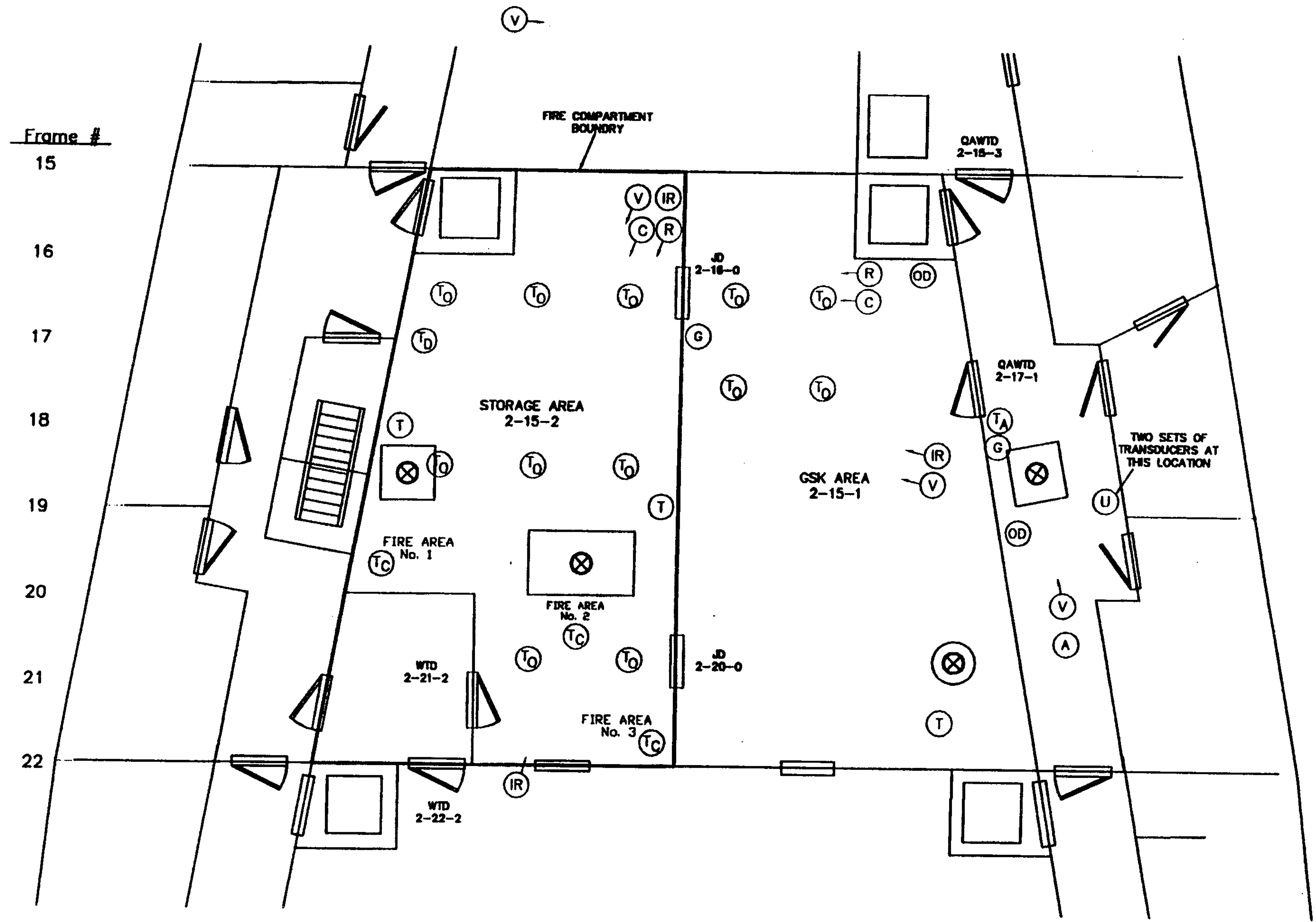


Fig. 14 – Second deck test area instrumentation layout plan view (FR 15–23)

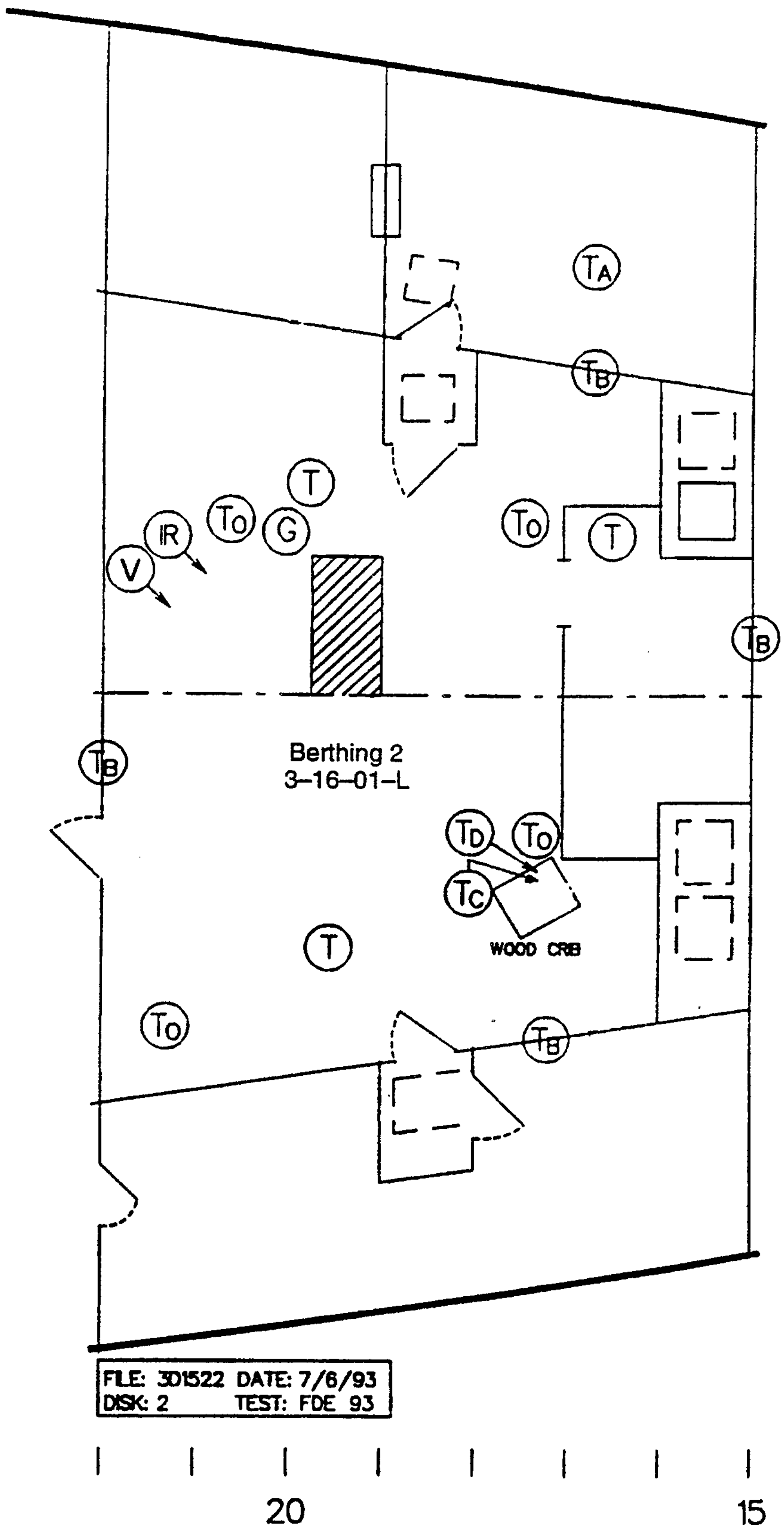


Fig. 15 — Third deck instruments between FR 15-22

with two thermocouple strings located at FR 18 on the port side (2-18-2) and FR 19 on the starboard side (2-19-0). In GSK and Storage the string thermocouples were mounted 0.46 m, 0.91 m, 1.4 m, 1.8 m, 2.3 m, and 2.7 m (18 in., 36 in., 54 in., 72 in., 90 in., and 108 in.) above the deck. Two thermocouples located at FR 18 (2-18-1) measured air temperatures in the starboard passageway. These thermocouples were mounted on the port bulkhead of the passageway at 0.46 m (18 in.) and 1.5 m (60 in.) above the deck. In Berthing 2, the air temperatures were measured by two thermocouple strings located at FR 19 on the port side of the compartment (3-19-2) and FR 19 on the starboard side of the compartment (3-19-1). Air temperature was measured in the Pump Room with a single thermocouple string located at FR 16 on the port side of the compartment (3-16-4). The string thermocouples in Berthing 2 and the Pump Room were positioned 0.46 m, 0.91 m, 1.4 m, 1.8 m, 2.3 m, 2.7 m, and 3.2 m (18 in., 36 in., 54 in., 72 in., 90 in., 108 in., and 126 in.) above the deck.

Thermocouples mounted 150 mm (6.0 in) below the overhead deck were located in the bays formed by the overhead structural framing immediately aft of FR 16, FR 18, and FR 20 in Storage and aft of FR 16 and FR 17 in GSK. These thermocouples measured temperatures of the hot gases in the overhead. The forward two bays in the Storage area had three thermocouples each, positioned 0.7 m, 2.2 m, and 3.6 m (28 in., 85 in., and 172 in.) from the centerline

Table 4. Instrumentation Key

Symbol	Definition
T	Thermocouple string
T_A	Air thermocouple
T_O	Overhead thermocouples
T_B	Bulkhead thermocouples
T_C	Crib thermocouples
T_D	Deck thermocouples
C	Calorimeter
R	Radiometer
U	Ultrasonic flowmeter
V	Visual camera
A	Audio
IR	Thermal image camera
OD	Optical density meter
G	Gas sampling

bulkhead. The aftmost bay in the Storage area and both bays in the GSK area had only two thermocouples each, positioned 0.7 m and 2.2 m (28 in. and 85 in.) from the centerline bulkhead. In Berthing 2, the overhead temperatures were measured by thermocouples positioned 150 mm and 460 mm (6.0 in and 18.0 in) below the overhead deck. These thermocouple pairs were located on the port and starboard sides of the compartment at FR 17 and FR 21.

Two thermocouples were extended down from the overhead at each fire source location to measure wood crib flame temperatures. These thermocouples were centrally located at the middle and 0.3 m (12 in.) above the top of the crib. The thermocouples were held in place by a steel chain suspended from the overhead.

To measure the surface temperature of the main and second decks, thermocouples were affixed to the underside and topside of the deck using nut and bolt assemblies. Deck temperatures were measured at one location (2-17-2) on the underside of the main deck, two locations (2-20-0 in Storage and 2-18-0 in GSK) on the topside of the second deck, and one location (3-20-1) on the underside of the second deck.

To measure the surface temperature of bulkheads, thermocouples were affixed to both sides of the bulkhead using nut and bolt assemblies. On the second deck, the temperature of the centerline bulkhead was measured at FR 17. In Berthing 2, the temperatures of the port and starboard bulkheads were measured at FR 17, and the aft bulkhead was measured at FR 22 along the centerline. The temperature of the forward bulkhead of the Pump Room was measured at FR 15, along the centerline.

3.4.2 Heat Flux Transducers

Total heat flux was measured in Storage and GSK with calorimeters. In Storage the calorimeters were located 0.9 m and 2.4 m (36 in. and 96 in.) above the deck at FR 16. The mounting brackets for these instruments were oriented such that both units viewed all three fire source locations. In GSK the calorimeter was located on the aft-facing bulkhead of the exhaust shaft supplying exhaust fan E1-15-1 (at FR 16). The mounting bracket for this instrument was oriented such that it viewed the forward joiner door (JD 2-16-0). All of the calorimeters had a full scale range of 0-57 kW/m^2 (0-5 $Btu/ft^2 \cdot s$). Radiometers to measure radiant heat flux were placed next to each of the calorimeters. The radiometers were mounted so that they had the same view as the calorimeters.

3.4.3 Optical Density Meters

Smoke obscuration was measured at two locations using LED type optical density meters (ODM). The first was mounted in GSK on the aft-facing bulkhead of the exhaust shaft supplying exhaust fan E1-15-1. The second meter was located in the starboard passageway at FR 20.

These instruments were mounted such that the beam projected horizontally at a height of 1.5 m (5.0 ft) above the deck. These instruments measured percent light transmitted and had a range of 0-100%.

3.4.4 Gas Sampling System

Continuous gas concentration measurements were made for oxygen, carbon dioxide, and carbon monoxide. Data was collected at four sampling locations for each test, including 0.3 m below the overhead and 0.6 m above the deck at 2-17-0 in GSK and 0.3 m below the overhead and 0.6 m above the deck at 3-19-2 in Berthing 2. The gas concentration measurements were made using Rosemount model NGA 2000 gas analyzers.

3.4.5 Ultrasonic Flowmeters

Ultrasonic flowmeters (Controlotron 9000 series) were installed at two locations to monitor the water flow from FP 2-19-1. Two sets of transducers were installed on the second deck at the fire plug in the starboard passageway. A third set of transducers was installed on the 01 level (01-47-2) to measure the flow through the well deck attack line. These units had a range of 760 Lpm (200 gpm).

4.0 FIREFIGHTING, DAMAGE CONTROL, AND PROTECTIVE EQUIPMENT

Standard Navy and commercially available firefighting, damage control, and protective equipment was used during this test series, including the following:

1. One-piece Navy firefighters ensemble (NSN 8415-01-300-6558) with DC/firefighters helmet (NSN 8415-01-271-8069), anti-flash hood (NSN 8415-001-268-3473) and firefighter's gloves (NSN 8415-01-296-5766).

2. Engineering coveralls (NSN 8405-01-204-5403)

3. Fireman's rubber boots (NSN 8405-00-753-5940)

4. Type 1 38 mm (1.5 in) 360 Lpm (95 gpm) vari-nozzle IAW MIL-N-24408 attached to 38 mm (1.5 in.) fabric jacketed hose (NSN 4210-00-255-6234).

5. Chemlights (chemically activated markers) Model 95270-53 manufactured by American Cyanamid.

6. Smoke curtains (NSN 4210-01-306-7826)

7. Smoke curtain clamps (1H0000-LL-CGA-2487).

8. NFTI (NSN 4210-01-21307310).

9. MSA Custom 4500 MMR (Mask Mounted Regulator) SCBA, MSA Part No. B-CM111-1M21-0.

10. Water motor fan with and without multipliers (RAMFAN 2000 manufactured by RAM Centrifugal Products.

11. Tubeaxial (box) fan (NSN 440-01-272-6060)

The MSA SCBA units were supplied with quick fill connections. A total of twenty-five cylinders of 30 and 45 minutes capacity and 5 cylinders of 60 minutes capacity were available for these tests. Twenty-five voice amplifiers were also available.

The compressor and filling connection arrangement shown in Fig. 16 was utilized during this test series. The Rope Locker (2-0-0-A) was used to house the high-pressure air compressors and the high-pressure air flasks. A fill connection was installed in the athwart ships passageway immediately aft of the former Paint Locker (2-0-2-A). The booster pump and a storage rack to hold all of the cylinders (Fig. 17) were installed in the former Paint Locker (2-0-2-A). This connection was similar to one of the connections on the USS TORTUGA, where the fill connection was located with the stored SCBA cylinders.

4.1 Test Participants

The Repair Team was composed of 16 personnel (both male and female) from the USS JOHN C. STENNIS (CVN 74). Table 5 shows the name and rate of each team member as well as their position for each test.

4.2 Firefighting Tactics

Two different attack methods were used during these tests. Specifically, the aggressive fog attack and a vertical attack technique were utilized. The aggressive fog attack was performed independently in test scba_03 and the vertical attack was performed independently in tests scba_04 and scba_05. In test scba_06 both methods were used to combat the combination fire scenario, where there were fires on the second and third decks. All of the firefighting actions, including investigation, boundary cooling, desmoking, and access and overhaul, were performed by US Navy personnel from the USS JOHN C. STENNIS (CVN 74). All of the firefighting tactics and procedures were in accordance with standard Navy procedures as described in NSTM 555 [14]. A detailed description of each of the attack methods follows.

The aggressive fog attack is a technique developed by the US Navy and is discussed in reference [6]. During this test series, the attack team consisted of a team leader, a nozzleman, and two hosemen. The attack team manned a hoseline at the fireplug (FP 2-19-1) in the starboard

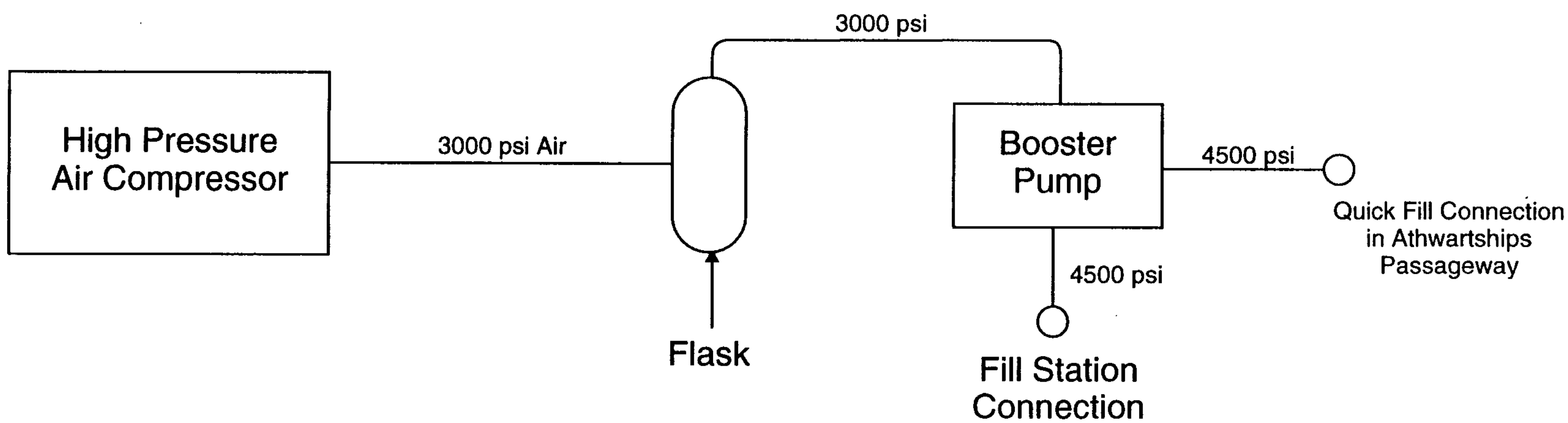


Fig. 16 — Schematic of high pressure air system

Fig. 17 — SCBA Storage in former Paint Locker (2-0-2-A)

Table 5. Summary of repair team members and positions

Rate/Rank and Name	Team Position			
	scba_03	scba_04	scba_05	scba_06
LCDR David E. Gilbert	Scene Leader	Scene Leader	Scene Leader	Scene Leader
DC3 John P. Yarnell	Boundaryman	Investigator	Nozzleman	Investigator
DCFA Degraffenreid	Boundaryman	Investigator	Hoseman	Hoseman
DC2 Douglas E. Lippert	Investigator	Boundaryman	Team Leader	Boundaryman
MMCS(SW) Herbert L. Broughton, Jr.	Access and Overhaul	Hoseman	Plugman	Team Leader
MR2 Cheryl J. Currier	Plugman	Hoseman	Desmoking	Desmoking
AN Bonnie M. Wilson	Hoseman	Boundaryman	Nozzleman	Boundaryman
DC2 Tamotha R. Cook	Investigator	Nozzleman	Investigator	Nozzleman
DC2 Michael J. Dugan	Nozzleman	Desmoking	Boundaryman	Team Leader
DC3 Matthew J. Smith-Wagner	Boundaryman	Nozzleman	Investigator	Nozzleman
DC1 Henry J. Deptula	Team Leader	Boundaryman	Desmoking	Desmoking
MM2 Mark A. Shaffer	Nozzleman	Team Leader	Desmoking	Desmoking
DC3 David E. Lipari	Desmoking	Hoseman	Hoseman	Hoseman
MM1 Alvin F. Sweet	Nozzleman	Boundaryman	Boundaryman	Hoseman
DC1 Laquita M. Victor	Desmoking	Plugman	Boundaryman	Boundaryman
IC1 Demetrius C. Bruno	Boundaryman	Desmoking	Hoseman	Investigator

passageway. The team then proceeded into GSK and positioned themselves at the forward joiner door (JD 2-16-0). Once the hoseline was charged, the team opened the joiner door and entered the fire compartment. Once inside the compartment, the nozzleman directed short fog bursts at the fire in the overhead using a medium angle fog pattern. The fog stream was directed at approximately a 45° angle to the overhead. These short fog bursts extinguished the fire in the overhead and provided an initial knockdown of the fires. The attack team was then able to advance well into the fire compartment and initiate direct attacks on all of the fire sources.

The vertical attack method used during this test series was developed during the 1993 Fleet Doctrine Evaluation Workshop [5] to combat a Class A fire in a below-decks, limited access space. The vertical attack included an indirect and a direct attack. Each attack was performed by a separate team. The indirect attack team, which consisted of a team leader, a nozzleman, and a

hoseman, performed an indirect attack from GSK. They manned a hoseline, which was supplied from fireplug (FP 2-19-1), in the starboard passageway. The team then entered GSK through WTD 2-17-1 to perform the attack. In tests scba_05 and scba_06 the team attempted to perform the indirect attack with the Fire Drill-2 [15], a pneumatic tool which is used to penetrate decks and bulkheads and indirectly inject water into the fire compartment. In both tests attempts to use the drill were unsuccessful and the drill had to be abandoned. In these cases, the indirect attacks were performed using a vari-nozzle with a wide angle fog pattern through the scuttle in GSK (WTS 2-20-1). The team performed several attacks by opening the scuttle, flowing water into the compartment for a relatively short time, and then closing the scuttle when the flow of water was secured. Following the indirect attack, the direct attack team began to attack the seat of the fire. The direct attack team consisted of a team leader, a nozzleman, and two hosemen. While the indirect attacks were being conducted, the direct attack team manned a hoseline, which was supplied from fireplug (FP 2-19-1), in the starboard passageway. The team then entered GSK through WTD 2-17-1 and then opened the forward joiner door (JD 2-16-0) into Storage. The team then advanced into Storage and positioned themselves near the hatch (WTH 2-20-0) to the third deck. When the indirect attacks were completed, the direct attack team opened the hatch and descended the ladder into the fire compartment. Once in the fire compartment, the nozzleman proceeded with a direct attack on the seat of the fire using a straight stream. In test scba_04, the direct attack handline was equipped with the EZ Pup firehose nozzle handling device [16].

4.3 Desmoking Tactics

In each of the firefighting tests (scba_03 to scba_06), active desmoking of the test area was performed by members of the Repair Team. In test scba_03, desmoking of the starboard passageway was accomplished using the "ventilation by fog" technique. A vari-nozzle was used to flow water through a scuttle (WTS 2-23-1) which opened to weather. In accordance with NSTM 555, water was flowed through the scuttle using a vari-nozzle with a 60° fog pattern. The nozzle was positioned such that the spray pattern covered 85 to 90 percent of the scuttle opening. The fog stream created a low pressure area at the opening which pulled the smoke out of the space. It is important to note that fans and blowers are preferred over the use of fog streams for desmoking because the fans and blowers do not require constant manning. Desmoking was also performed in the ship fitter's shop, using the scuttle (WTS 1-19-2) which opened into Storage. In Test scba_03 a RAMFAN was connected to the scuttle to desmoke the second deck.

In Tests scba_04 desmoking of the starboard passageway was accomplished using a vari-nozzle, as in Test scba_03. Desmoking was also performed from the main deck using a RAMFAN. The RAMFAN was initially connected to the scuttle (WTS 1-19-2) in the ship fitter's shop to desmoke the second deck. Once the environment improved, the trunk was then lowered down to the second deck hatch to desmoke Berthing 2. The scuttle in GSK (WTS 2-20-1) was used to provide the make-up air supply.

In test scba_05, the vari-nozzle was again used to desmoke the starboard passageway. However, in this test, a box fan was also placed near Repair 2 with the air stream blowing aft into the starboard passageway. Desmoking from the main deck was performed using a combination of box fans. A single box fan was placed over the scuttle (WTS 1-19-2) in the ship fitter's shop and two box fans were stacked in the door (WTD 1-15-1) opening to weather. A box fan was also placed on the scuttle (WTS 2-20-1) in GSK with air stream directed into Berthing 2.

The same desmoking tactics used in Test scba_05 were also used in Test scba_06, with one exception. In addition to the vari-nozzle, the EZ Pup firehose nozzle handling device [16] was also used.

4.4 Test Procedures

Prior to the first test, the test participants were instructed in the proper use of the SCBAs and were provided training in aggressive fog and vertical entry tactics. The pretest checklist was completed. The fire pump was brought on line to 827 kPa (120 psi). The proper ventilation configuration for the fire threat was aligned including fan settings and accesses to the spaces. Video recorders were started and data acquisition was initiated. After it was established that the data acquisition was functioning properly, the test director gave the command to have the initiating fuel poured into the pans located beneath the cribs. Once fueling was completed the fires were ignited and the fire was called away over the 1MC system. This was the signal for the Repair Party to report to Repair 2 and dress-out. The preburn period was approximately 10 min for each test. During the preburn period, fresh air to the fire space was throttled to regulate the fuel burning rate. As team members completed their final dress-out, they reported to their respective stations. When all of the attack team members were ready to enter the fire compartment (i.e., fully dressed out and breathing apparatus operating properly), all watertight doors being used to throttle fresh air into the fire compartments were closed. The attack team proceeded from Repair 2 to the starboard passageway, where they manned and charged the attack hoselines, and proceeded to attack the fire. Firefighting tactics and procedures, including investigation, boundary cooling, and smoke control were in accordance with standard Navy procedures as described in NSTM 555 [14].

5.0 TEST RESULTS

Graphical presentation of the temperature, total and radiant heat flux, smoke obscuration, and gas analysis data for a representative test (Test scba_03) is presented in Appendix A. These graphs present the data from the time of ignition to the time that data acquisition was stopped.

Measures of performance developed and used during previous studies [5], [6],[8] were used to provide a quantitative indication of the heat, steam, and fire threats experienced by the attack team. The following measures were used to determine the relative success of the firefighting effort:

1. Crib thermocouples were used to measure knockdown and extinguishment of the crib fires;

2. The average of the overhead thermocouples was used to measure the effectiveness of upper layer gas cooling;
3. The average of upper string thermocouples versus the average of lower string thermocouples were used to measure disturbances in the compartment thermal balance;

4. The calorimeter data was also used to measure disturbances in the compartment thermal balance, as well as the total thermal insult to personnel; and

5. Water flow data, particularly total flow, were used as a measure of control effectiveness.

Graphical presentation of the measures of performance data is provided in Appendix B. These graphs present the data from the time the attack team left the Repair 2 area to the time that data acquisition was stopped.

Brief narratives for each of the firefighting tests are included in the following sections. These narratives were based on data obtained from the instrumentation, radio communications with the safety team, and post-test debriefs. A timeline of key events for each of the four firefighting tests is included in Appendix C.

5.1 Heat Threat and Fire Insult

Table 6 provides a summary of key temperature values for the time period 7:00 to 12:00 minutes after ignition. This table includes the average overhead temperature in each of the three compartments and the average temperature of each wood crib. The time period 7:00 to 12:00 minutes was chosen because it represents the true growth period of the fire, after the initiating fuel was consumed. Table 7 provides a comparative summary of the conditions in the fire compartment before and after the first indirect or direct attack for each test. This Table includes the average and maximum overhead temperatures in the fire compartment (Storage or Berthing 2) as well as the average temperatures of each of the wood cribs.

The data presented in Tables 6 and 7 provide an indication of the heat threat and steam insult the attack team was exposed to at various times during the firefighting evolution.

Table 6. Temperature and Total Heat Flux Values for Time Period 7:00 to 12:00 after Ignition

Test No.	Average Overhead Temperatures (°C(°F))			Maximum Wood Crib Temperatures (°C(°F))				Maximum Total Heat Flux (kW/m² (Btu/ft²·s))		
	GSK	Storage	Berthing 2	Crib 1	Crib 2	Crib 3	Crib 4	GSK	Storage 0.9 m (3.0 ft)	Storage 2.4 m (8.0 ft)
scba_03	80 (176)	589 (1092)	N/A	474 (885)	514 (957)	692 (1278)	N/A	0	1.2 (13.6)	2.2 (25.0)
scba_04	66 (151)	98 (208)	245 (473)	N/A	N/A	N/A	461 (862)	0.1 (1.1)	0.1 (1.1)	0
scba_05	70 (158)	123 (253)	395 (743)	N/A	N/A	N/A	473 (883)	0.1 (1.1)	0.2 (2.2)	0.2 (2.2)
scba_06	92 (198)	513 (955)	326 (619)	214 (417)	402 (756)	527 (981)	551 (1024)	0.1 (1.1)	0.6 (6.8)	1.0 (11.4)

Table 7. Comparative Summary of Conditions in Fire Compartment Before and After Initial Attack

Test No.	Prior to Attack						After Initial Attack					
	Avg. OH (°C (°F))	Max. OH (°C (°F))	Crib 1 (°C (°F))	Crib 2 (°C (°F))	Crib 3 (°C (°F))	Crib 4 (°C (°F))	Avg. OH (°C (°F))	Max. OH (°C (°F))	Crib 1 (°C (°F))	Crib 2 (°C (°F))	Crib 3 (°C (°F))	Crib 4 (°C (°F))
scba_03	609[1] (1128)	735[1] (1355)	477 (891)	603 (1117)	545 (1013)	N/A	413[1] (775)	720[1] (1328)	270 (518)	500 (932)	520 (968)	N/A
scba_04	345[1] (653)	400 (752)[1]	N/A	N/A	N/A	530 (986)	250[1] (482)	290[1] (554)	N/A	N/A	N/A	300 (572)
scba_05	275[2] (527)	290 (554)[2]	N/A	N/A	N/A	620 (1148)	230[2] (446)	240[2] (464)	N/A	N/A	N/A	590 (1094)
scba_06 Storage Berthing 2	522 (972) 387 (729)	774 (1425) 448 (838)	246 (475) N/A	483 (901) N/A	408 (766) N/A	N/A 750 (1382)	267 (513) 255 (491)	300 (572) 270 (518)	200 (392) N/A	170 (338) N/A	190 (374) N/A	N/A 180 (356)

1 Overhead temperature in Storage
2 Overhead temperature in Berthing 2

Furthermore, the data in Table 7 shows the effectiveness of the initial attack in cooling the compartment and knocking down the wood cribs.

In each of the tests, with the exception of Test scba_05, the initial attack resulted in a significant and immediate reduction in the overhead and crib temperatures. In Test scba_05, approximately 10 minutes after the team left Repair 2, there was an immediate decrease in the temperature measured 150 mm (6 in.) above the wood crib. There was also a gradual decrease in the overhead temperatures. These reductions in temperature were due to the closing of WTD 3-22-1 and the two second deck scuttles (WTS 2-20-1 and WTS 2-20-2). The data shows that the first indirect attack with the vari-nozzle, which took place more that 16 minutes after the team left Repair 2, had very little effect on the overhead temperatures. At the time of this attack, the threat from the wood crib was significantly reduced. Furthermore, water from the indirect attacks was not being placed directly on the crib. This also contributed to the absence of an immediate decrease in either the crib or overhead temperatures.

The fire scenario used in Test scba_03 was the same as that used during the US/UK Navy Firefighting and Personal Protection Equipment and Procedures Evaluations. Examination of the data from Test scba_03 shows good agreement with the data presented in reference [7]. The vertical attack scenario used in this test series was not comparable to that used during Class A Fire/Vertical Attack Workshop [5].

5.2 Results of Test scba_03

The fire scenario used in this test was the Class A post-flashover scenario. The fire was attacked using the aggressive fog technique. A team of two investigators initially entered the starboard passageway and then proceeded into GSK. At this time the fires had been burning for 7 min 20 sec and the overhead temperatures in GSK were approximately 80°C. The investigators returned to the Repair 2 area and reported their findings to the on-scene leader. Approximately two minutes after the investigators initially entered GSK, the attack team entered the compartment. The attack team proceeded through GSK and entered Storage via the forward joiner door (JD 2-16-0). At the time that the team entered Storage (10 min 9 sec after ignition), the average overhead temperature in Storage was 600°C and the average air temperature high and low in Storage were approximately 550°C and 375°C, respectively. The total heat fluxes measured 0.9 m (3.0 ft) and 2.4 m (8.0 ft) above the deck at the joiner door were 11 kW/m^2 (1 Btu/ft$^2\cdot$s) and 23 kW/m^2 (2 Btu/ft$^2\cdot$s), respectively. The attack team discharged a short fog burst into the overhead at an angle of approximately 45°. This burst resulted in an immediate reduction in the temperatures of all three wood cribs and the average overhead and air temperatures. The average overhead temperature was reduced to 400°C and the average air temperatures, high and low in the compartment, were reduced to 300°C and 200°C, respectively. After the fog burst, the attack team backed out of Storage to the starboard passageway. While the team was in the starboard passageway, the temperatures in the fire compartment, with the exception of the crib temperatures, returned to nearly the same levels as before the attack. The team reentered Storage 3 min 14 sec after the first fog attack. The team performed two fog bursts, producing similar results as the first attack, and then attempted to advance into the compartment to begin the direct

attacks. Due to the steam insult, the team was forced to back out to the starboard passageway and regroup. About 10 minutes after the team backed out of Storage for the second time, the team reentered the fire compartment. During the time prior to reentry, the team members were resting and refilling their SCBA cylinders. The team reentered the fire compartment and performed a single straight stream attack and then backed out to GSK. Less than a minute after the last attack the team reentered the fire compartment and verified that all three of the fires were under control. The fires were verified under control 29 min 58 sec after the fire was called away. The attack team backed out to the foc's'le and the overhaul team proceeded with overhauling the fires. The spaces were desmoked and then gas free certified using MSA 4 gas analyzer and the test was secured.

5.3 Results of Test scba_04

The fire scenario for this test involved two wood cribs located in Berthing 2. As discussed earlier one of these cribs was located in the overhead and was not manually ignited. In fact, the crib in the overhead did not ignite during the entire test. The fire was attacked using the vertical attack protocol discussed earlier. The fires were ignited by the safety team and after an eight minute preburn the fire was called away. The Repair Team arrived at Repair 2 approximately one minute after the fire was called away. The team performed final dress out and donned SCBAs in the Repair 2 area. About five minutes after arriving at Repair 2, a team of investigators proceeded into the test area, including the GSK and Storage compartments. The investigators backed out to the starboard passageway and reported their findings. The indirect attack team entered GSK 8 min 40 sec after the fire was called away. The team performed indirect attacks through the scuttle in GSK (WTS 2-21-1) with a vari-nozzle. The average overhead temperatures in Berthing 2 were 340°C and the average air temperatures, measured high and low in the compartment, were 400°C and 150°C, respectively. After the first indirect attack, which consisted of a short fog burst directed at the crib, the average overhead temperatures were reduced to 240°C and the average air temperatures were approximately 250°C. Following the first indirect attack, the indirect attack team backed out to the starboard passageway. While the team was in the starboard passageway, there was no significant increase in either the air or overhead temperatures in Berthing 2. Approximately 1 min 23 sec after first attack, the indirect attack team reentered GSK and performed a second attack. The second attack caused a further reduction in the air and overhead temperatures. After the second attack the average overhead temperature was 200°C and the average air temperatures, measured high and low, were 200°C and 70°C, respectively. Again, the team backed out to the starboard passageway following the indirect attack. As with the first attack, there was no significant increase in the compartment temperatures following the second indirect attack. About 1 min 20 sec after the second attack the team reentered the compartment for the third indirect attack. Although there were only minor decreases in the overhead and air temperatures, the fire was extinguished with this attack. (Note - the fire fighters in a smokey environment would not know this, this was information known only to the control room). A fourth indirect attack was performed before the direct attack team opened the hatch (WTH 2-20-2) and entered the fire compartment. The direct attack team entered Berthing 2, at which time the average overhead temperature was about 190°C. The initial direct attack was with a wide angle fog pattern. The use of a fog stream resulted in a reflash of

the fire when oxygen was reintroduced to the compartment. The nozzleman switched to straight stream and proceeded to extinguish the fire. The test area was cleared of smoke and gas free certified before the test was secured.

5.4 Results of Test scba_05

The fire scenario used in Test scba_05 was the same as that used in Test scba_04 except that a diesel pan fire was used to attempt to create a low visibility environment. The diesel fire was ignited by the safety team and allowed to burn for 6 min 26 sec before the crib fire was ignited. The pan fire burned for a total of 11 min 13 sec before the fire burned out. About 8 min 19 sec after the crib fire was ignited, the fire was called away. The team arrived at the Repair 2 area less than one minute after the fire was called away and began donning SCBAs and performing final dress out. The team of investigators entered GSK 9 min 22 sec after arriving at Repair 2. By this time visibility had been restored in GSK and the starboard passageway. The investigators proceeded into Storage and then returned to the starboard passageway to report their findings. The indirect attack team entered GSK a little less than two minutes after the investigators had initially entered GSK. At this point the fire had been burning for 20 min 7 sec. The average overhead temperature was 380°C in Berthing 2 and 60°C in GSK. The average air temperatures measured high and low were 470°C and 230°C in Berthing 2 and 68°C and 58°C in GSK. The indirect attack team made two unsuccessful attempts to penetrate the deck and perform an indirect attack using the Fire Drill-2. During the first attempt, the water was inadvertently turned on before the penetration was complete. This resulted in a momentary buildup of steam in the area of the penetration. The water was secured and the drilling continued. At this time, the air, overhead, and crib temperatures in Berthing 2 began to decrease due to the closure of WTD 3-22-1 and the two second deck scuttles (WTS 2-20-1 and WTS 2-20-2). Approximately three minutes after the initiation of drilling, the set screws on the drill bit loosened and the penetration had to be halted. The drill was taken into the starboard passageway, where the safety team reassembled the drill. The indirect attack team reentered GSK for a second attempt with the drill, which also failed. The penetration was nearly complete when the set screws again loosened. At this point, the Fire Drill-2 was removed from the compartment and a vari-nozzle was retrieved to perform the indirect attacks. A total of 6 min 56 sec elapsed from the time the indirect attack team initially entered GSK to the time that use of the Fire Drill-2 was abandoned. Another two minutes passed before the first indirect attack was performed with the vari-nozzle. The indirect attack team performed a total of four indirect attacks with the vari-nozzle. Based on the observations of the safety team members located in Berthing 2, water from the four indirect attacks was not being directed on the wood crib. After the fourth indirect attack, the fire was believed to have burned out. The direct attack team proceeded into Berthing 2 and verified that the fire was extinguished. Another team entered the fire compartment and began to overhaul the fire.

5.5 Results of Test scba_06

The fire scenario used in this test was a combination of those used in tests scba_03 and scba_04. The fire attack used to combat this fire scenario was a combination of the tactics used in

the same tests. The three second deck fires were ignited by the safety team and allowed to burn for 4 min 48 sec before the third deck crib was ignited. The fire was called away 2 min 47 sec after the third deck crib was ignited. The team made their way to Repair 2 in less than a minute and began donning SCBAs and performing final dress out. A team of investigators entered GSK approximately seven minutes after arriving at Repair 2. The average overhead temperature in GSK was nearly 100°C and the average air temperature, measured high and low, in the space were 95°C and 68°C, respectively. The team backed out to the passageway and reported their findings. The direct attack team entered GSK and proceeded through the compartment into Storage. The average overhead temperature in Storage was about 520°C and the total heat fluxes, measured 0.9 m (3.0 ft) and 2.4 m (9.0 ft) above the deck, at the joiner door were 7.9 kW/m^2 (0.7 $Btu/ft^2 \cdot s$) and 1.1 kW/m^2 (0.1 $Btu/ft^2 \cdot s$). The direct attack team performed a single fog burst and then backed out to the passageway. The fog burst caused a significant reduction in the temperatures of cribs 2 and 3. As expected, crib 1 was beginning to lose its intensity at this point, so, the effects of the fog burst were not as significant. The average overhead temperature in the compartment decreased from 530°C to approximately 300°C as a result of the fog burst. After the direct attack team backed out of the fire compartment, the indirect attack team entered GSK and prepared to perform an indirect attack with the Fire Drill-2. As in Test scba_05, the drill operation was unsuccessful due to the loosening of the set screws, which held the drill bit in place. The indirect attack team removed the drill from GSK and setup to perform an indirect attack with a vari-nozzle through the scuttle (WTS 2-21-1) in GSK. The team performed two indirect attacks before backing out to the starboard passageway. This resulted in a significant reduction in the temperature of crib 4. The overhead temperature in Berthing 2 was also greatly reduced, from 380°C to 240°C. The direct attack team reentered Storage nearly 12 minutes after backing out of the compartment following the initial attack. When the team reentered Storage the average overhead temperature was approximately 300°C with cribs 2 and 3 still burning. The team advanced into the compartment and performed a direct attack which extinguished cribs 2 and 3. The direct attack team backed out to the starboard passageway while the indirect attack team prepared to perform another attack through the scuttle. The team performed the third indirect attack and extinguished crib 4 9 min 22 sec after the second indirect attack. The direct attack team proceeded through GSK into Storage and opened the hatch (WTH 2-20-2) to Berthing 2. The team entered Berthing 2 and verified that crib 4 was extinguished. At this time the indirect and direct attack teams backed out to the foc's'le while other team members began overhauling the second and third deck fires. The space was desmoked and gas free certified before the test was secured.

5.6 Results of SCBA Evaluation

Following each test, debriefs were conducted to review the events of each test and to obtain feedback from the fleet participants. Although the results of the SCBA evaluation are discussed in a separate report [17], the participants made several comments with respect to the SCBAs that are worth mentioning here. First, the majority of the participants preferred wearing the SCBA on their backs as opposed to wearing an OBA on their chest. The fact that the SCBA was mounted on the back made movement, especially bending, much easier. It was mentioned, however, that while wearing an SCBA and a helmet, it is not possible to look straight up without

adjusting or removing the helmet. As the head tilts up the helmet starts to hit the SCBA cylinder. Second, all of the participants, if given the option, preferred to quick-fill their cylinders instead of changing out bottles. The process of quick-filling the cylinders is physically less demanding than changing out cylinders and allows the team members an opportunity to rest. It was suggested that if enough quick-fill connections were installed on a ship that cylinder change out would not be necessary.

Several problems associated with the SCBAs were noted during this test series. First, there were several instances where team members had problems maintaining a good seal throughout the test. There are several reasons why this may have occurred. Inadvertent loosening of the mask may have occurred while the fire fighter was putting on a flash hood. The loss of a good seal may have resulted from perspiration. It is also possible that the mask was not the appropriate size for the individual. All of the masks used during this test series were medium size. Second, nearly all of the fleet participants experienced difficulty with their voice amplifier during the test series. Participants experienced feedback and were forced to turn off the voice amplifiers or had amplifiers which did not operate at all. Third, all of the participants had difficulty operating the tabs on the side of the regulator and the bypass relief valve while wearing gloves. The size of the gloves made operating the tabs and the relief button nearly impossible.

The participants also commented on which bottle sizes should be used for certain tasks. It was widely agreed, although not unanimously, that the attack team should wear the 45 minute bottles. This is a result of the amount of time the team required to remain on an air supply, as well as the physical effort required to perform the tasks required of the attack team. The participants' opinions were more divided on which bottle size should be used to perform boundary cooling, investigation, and desmoking. Some participants thought that the 45 minute bottle was too cumbersome to be used by personnel required to perform a significant amount of movement (e.g., travel up and down ladders). Other personnel preferred the 45 minute bottle over the 30 minute bottle because of the extra air time that the larger bottle provided. Due to the size and weight of the cylinder, the participants felt that the 60 minute cylinder could not be used for any activity. A more detailed discussion of these results is provided in reference [17].

In Test scba_05, participants noted that the breathing air was "real warm." This was a result of prolonged exposure (15-20 min) in the hot Berthing 2 area. Participants noted that the air in their cylinders was drawn down to a low pressure in this situation. No participant indicated that this affected their fire fighting ability.

It was observed in Test scba_06 that with only one compressor on line (60 cfm) air and the flask empty supply could not keep up with the quick fill connection. The requirement to supply air to the quick fill booster pump reduced the compressor supply capacity to the quick fill connection.

6.0 SUMMARY OF FINDINGS

Based on qualitative data collected during the posttest debriefs, the following trends and issues were identified:

1. The participants appeared to prefer the fit of the SCBA over the OBA. Carrying the weight of the SCBA on the back and hips is more comfortable than the chest mounted OBA.

2. All of the participants preferred using the quick-fill connection to refill the SCBA cylinders over the process of changing out cylinders.

3. Several of the fleet participants stated that they were unable to maintain a good seal with the MSA mask.

4. In each test there were a few participants that experienced difficulty with the voice amplifier installed in the mask. The cause of these problems was unknown.

5. Due to the size of firefighting gloves, some of the buttons and tabs on the MSA mask were difficult, if not impossible, for the firefighters to manipulate.

6. The participants that handled the EZ Pup firehose nozzle handling device, used in Test scba_06, believed that the nozzle would be of use in an open area such as a flight deck, but of little use in confined spaces such as passageways and small compartments.

7. The EZ Pup firehose nozzle handling device offered no significant improvement for handline operations (see reference [16] for more details).

8. The Fire Drill-2 which was used to perform indirect attacks in Tests scba_05 and scba_06 did not perform properly during these tests (see Ref. [1] for more details).

7.0 ACKNOWLEDGMENTS

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Appendix A

Data from Representative Test (Test scba_03)

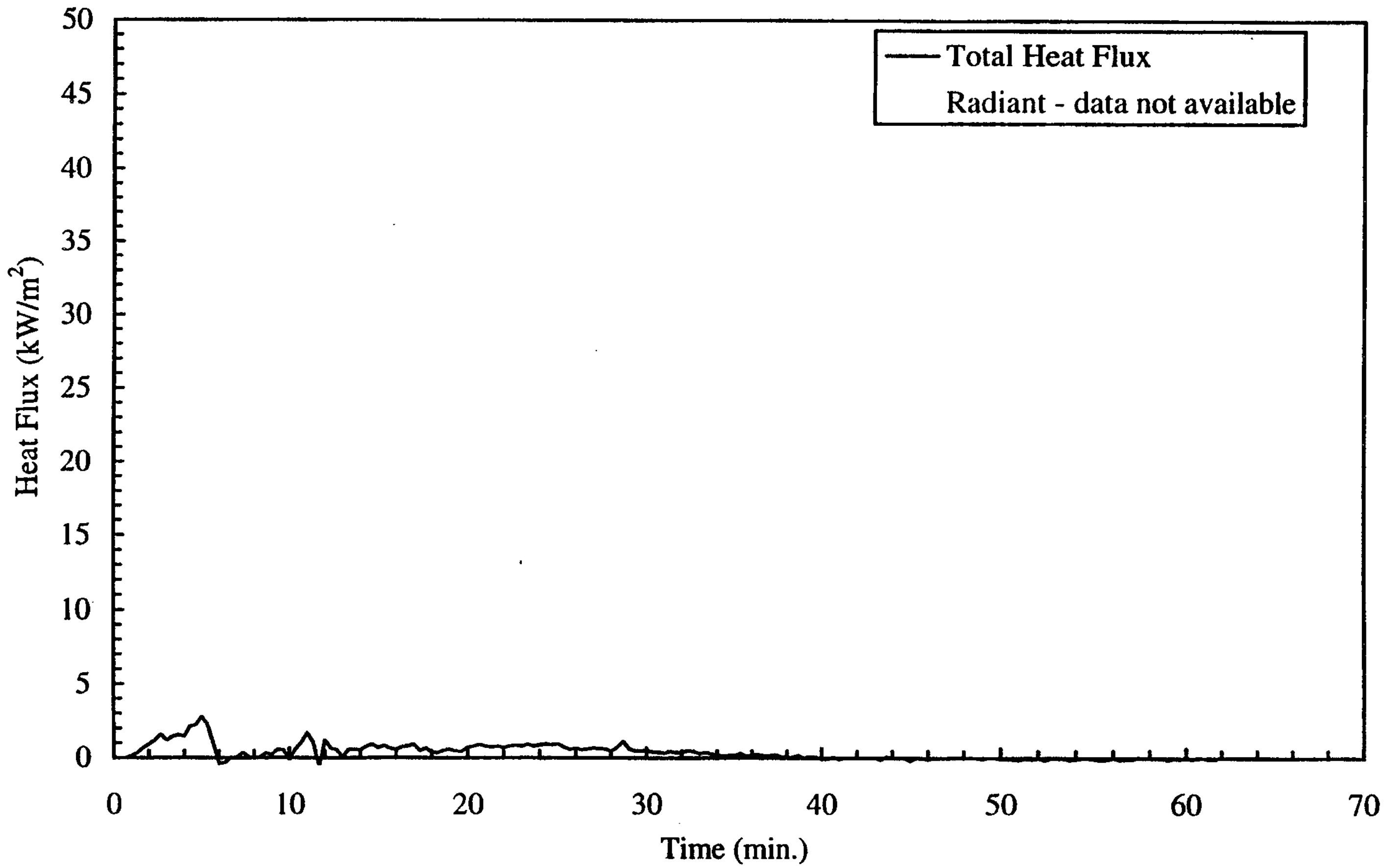

Fig. A1 - Total and radiant heat flux measured in GSK

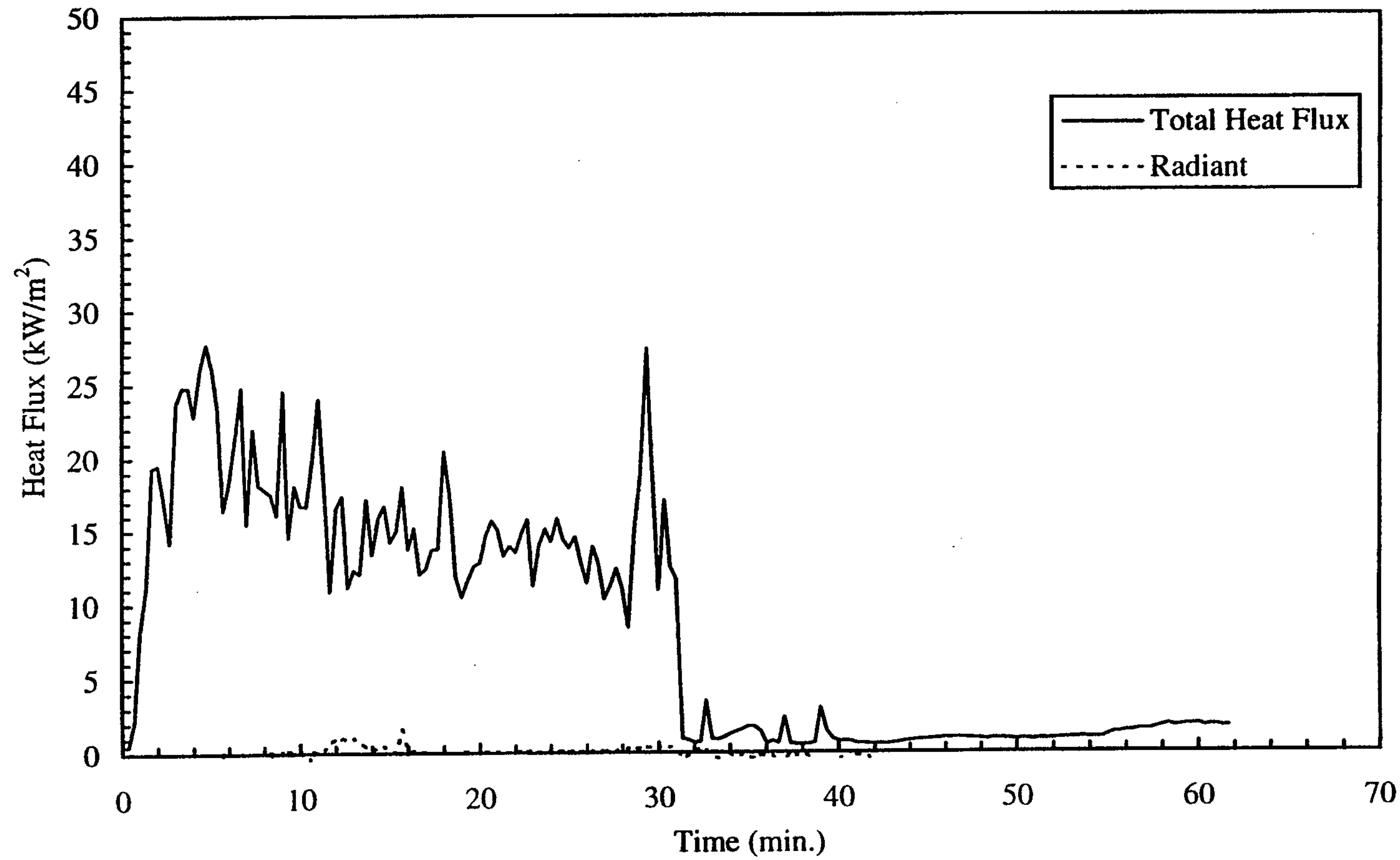

Fig. A2 - Total and radiant heat flux measured 2.4 m (8.0 ft) above the deck in Storage

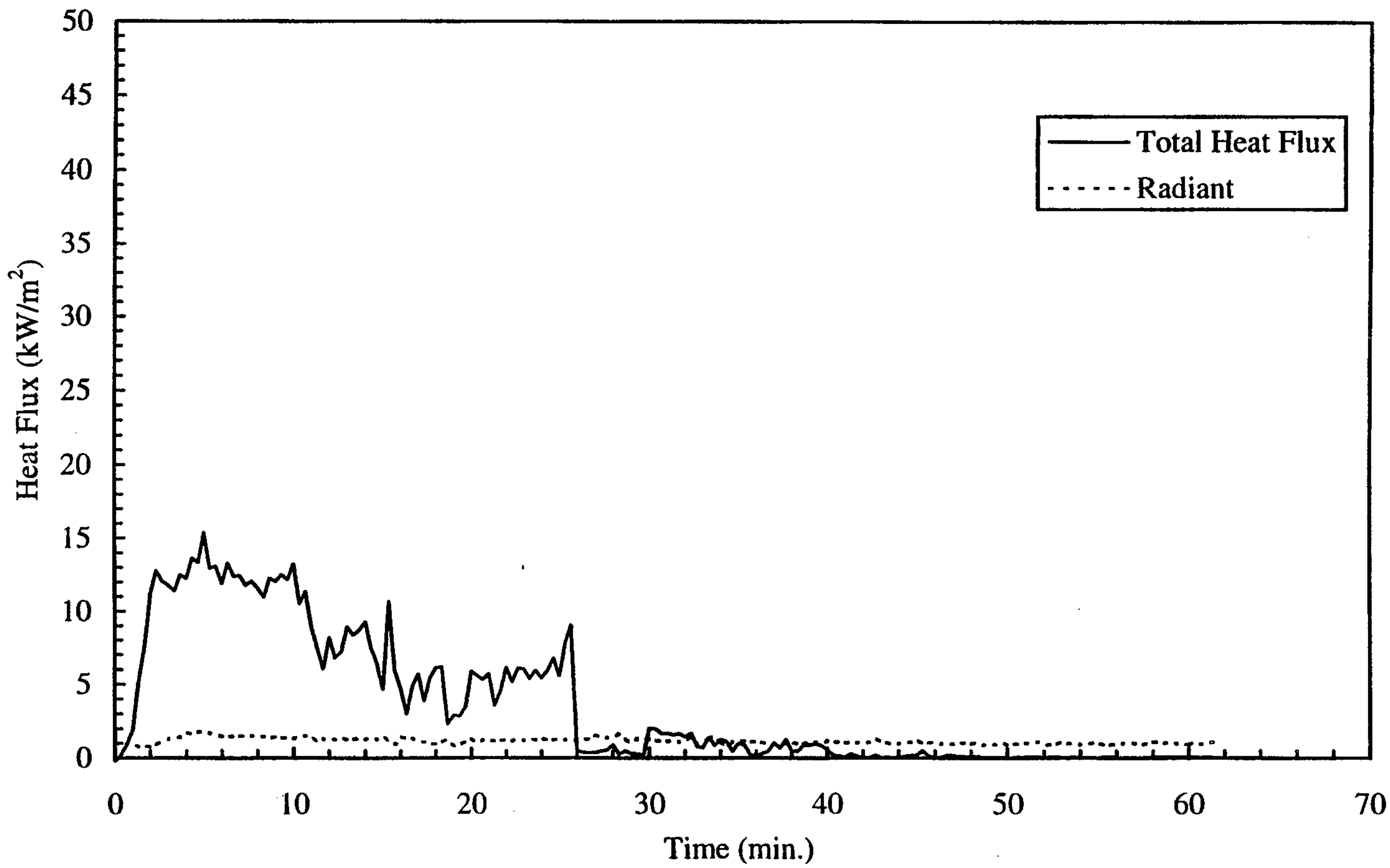

Fig. A3 - Total and radiant heat flux measured 0.9 m (3.0 ft) above the deck in Storage

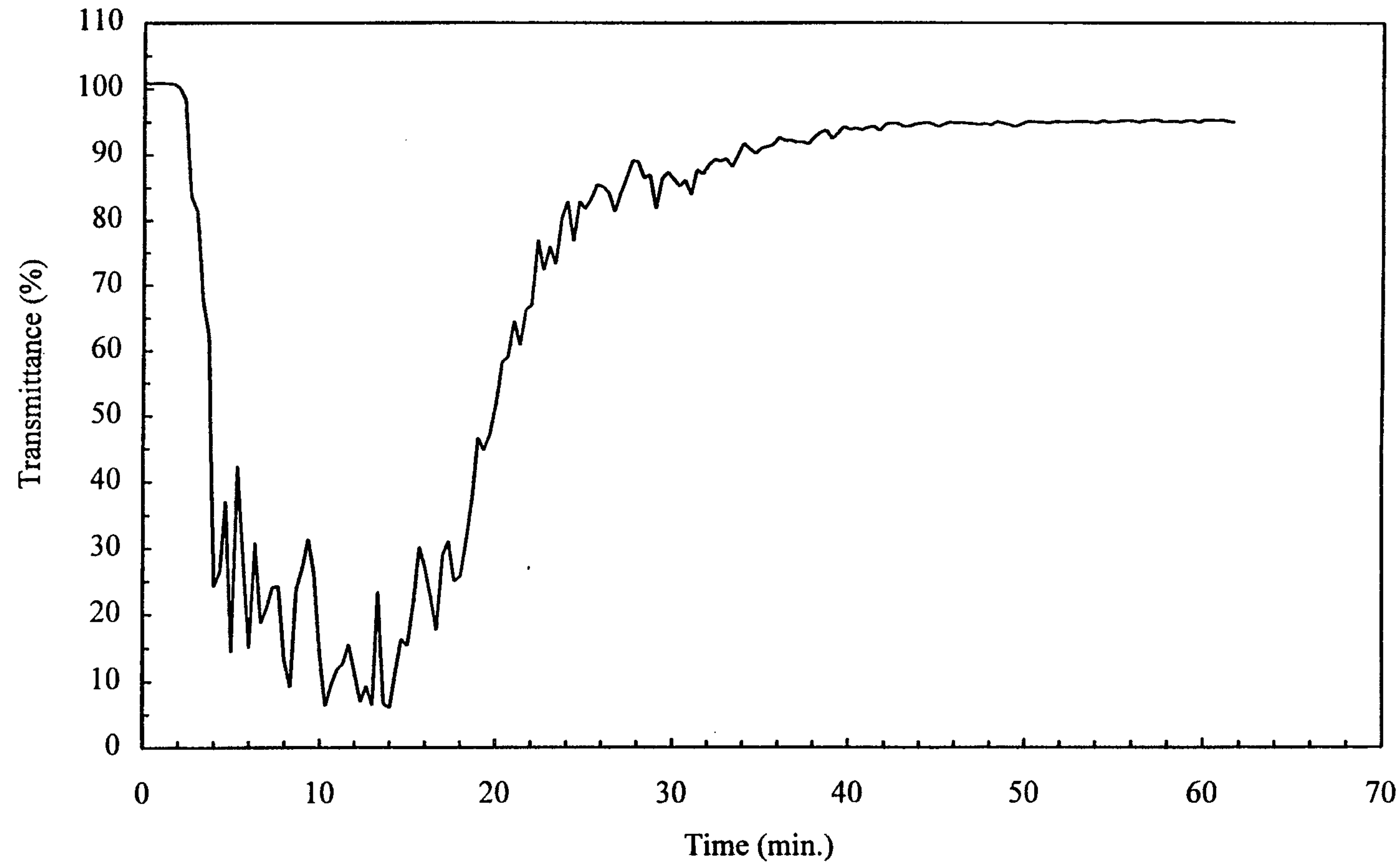

Fig. A4 - Transmittance measured 1.5 m (5.0 ft) above the deck in the starboard passageway

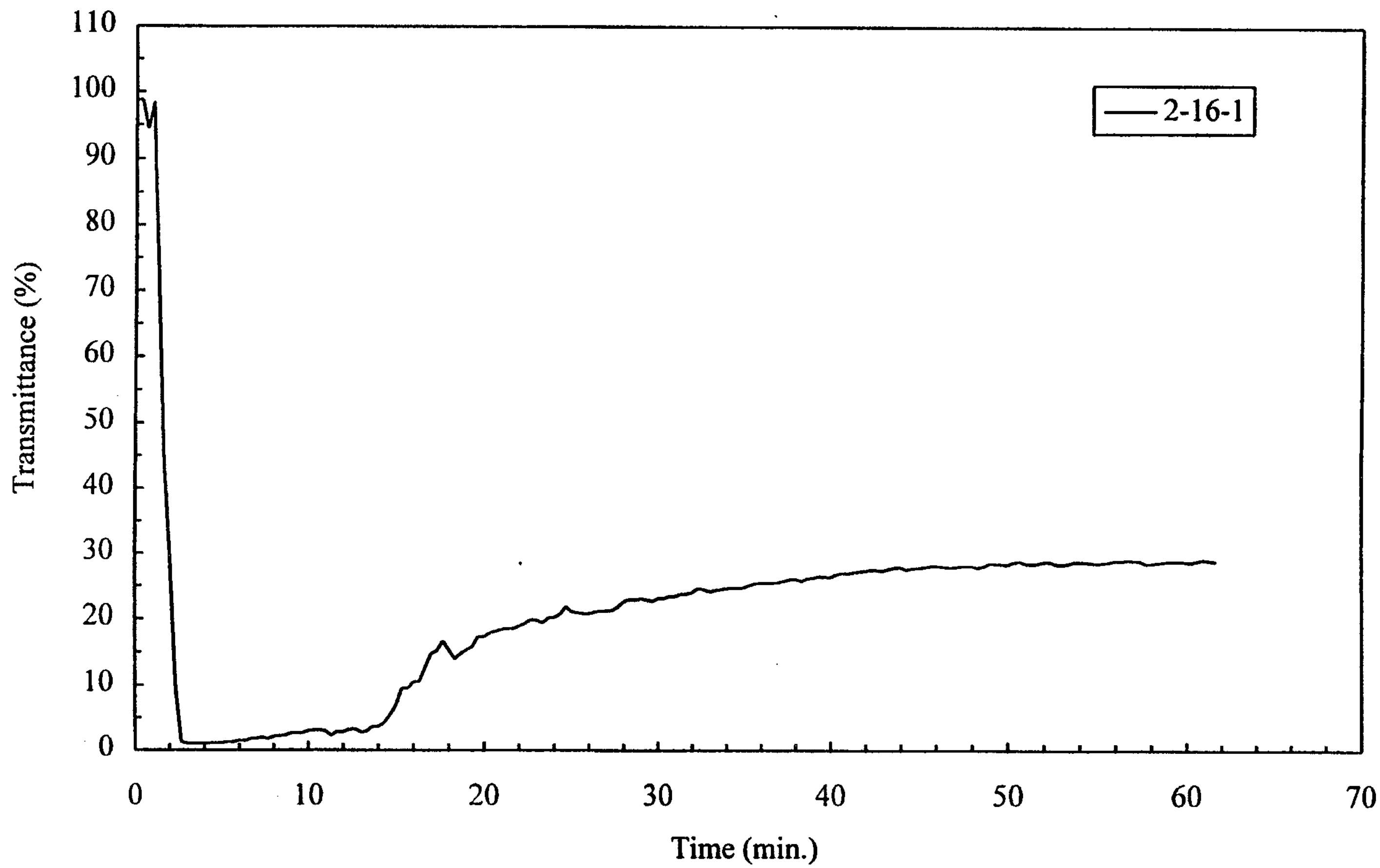

Fig. A5 - Transmittance measured 1.5 m (5.0 ft) above the deck in GSK

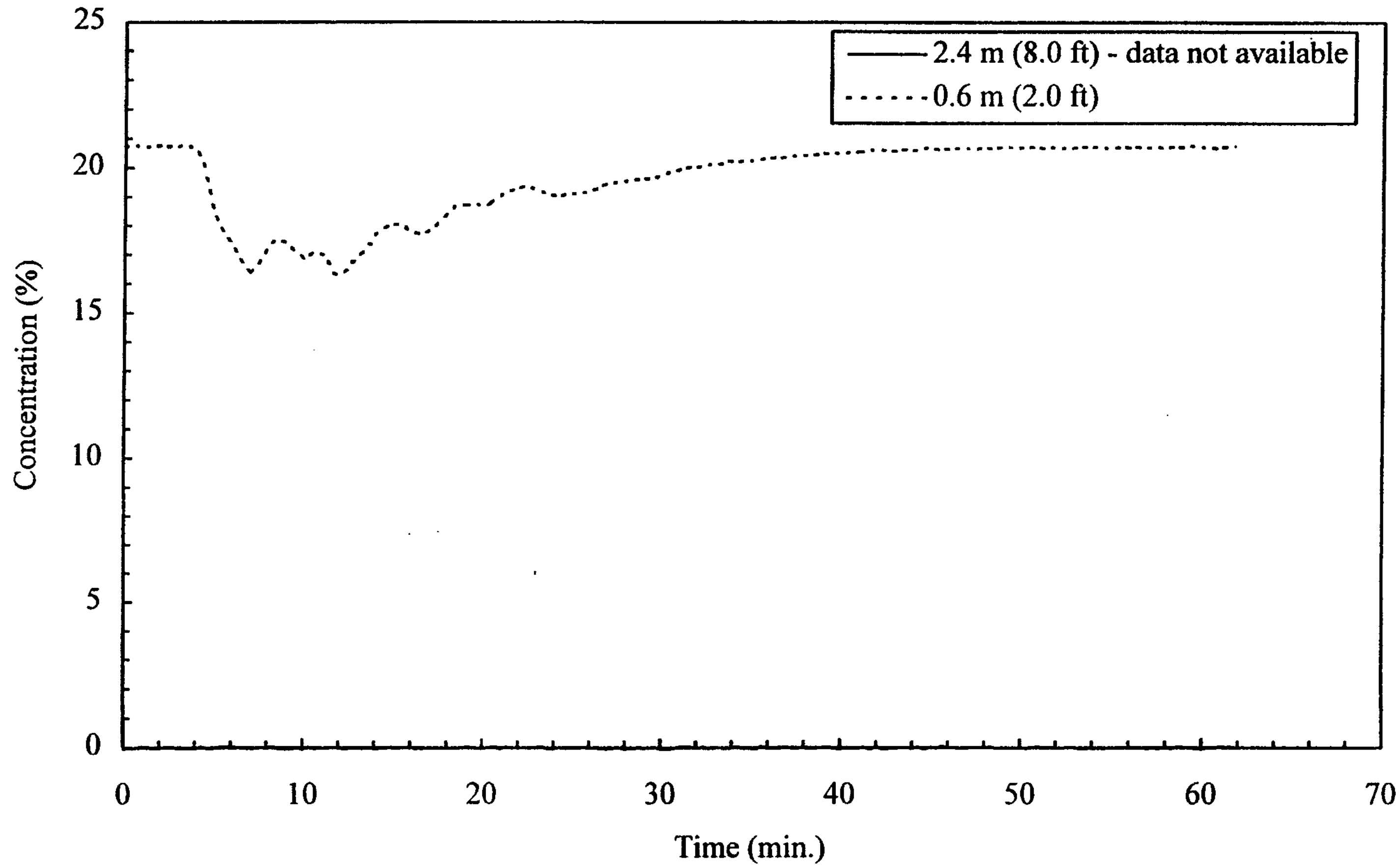

Fig. A6 - Oxygen concentration in GSK

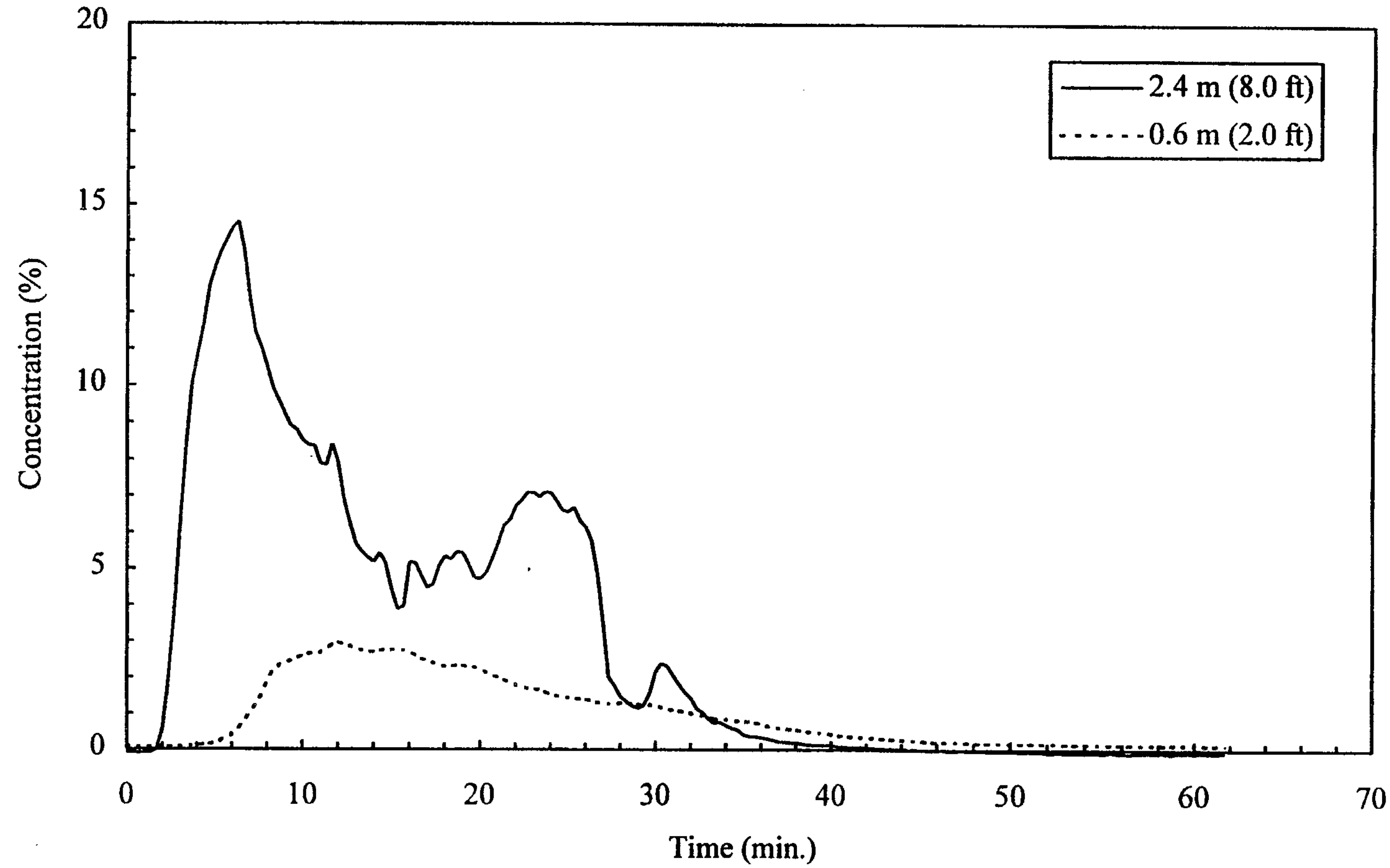

Fig. A7 - Carbon dioxide concentration in GSK

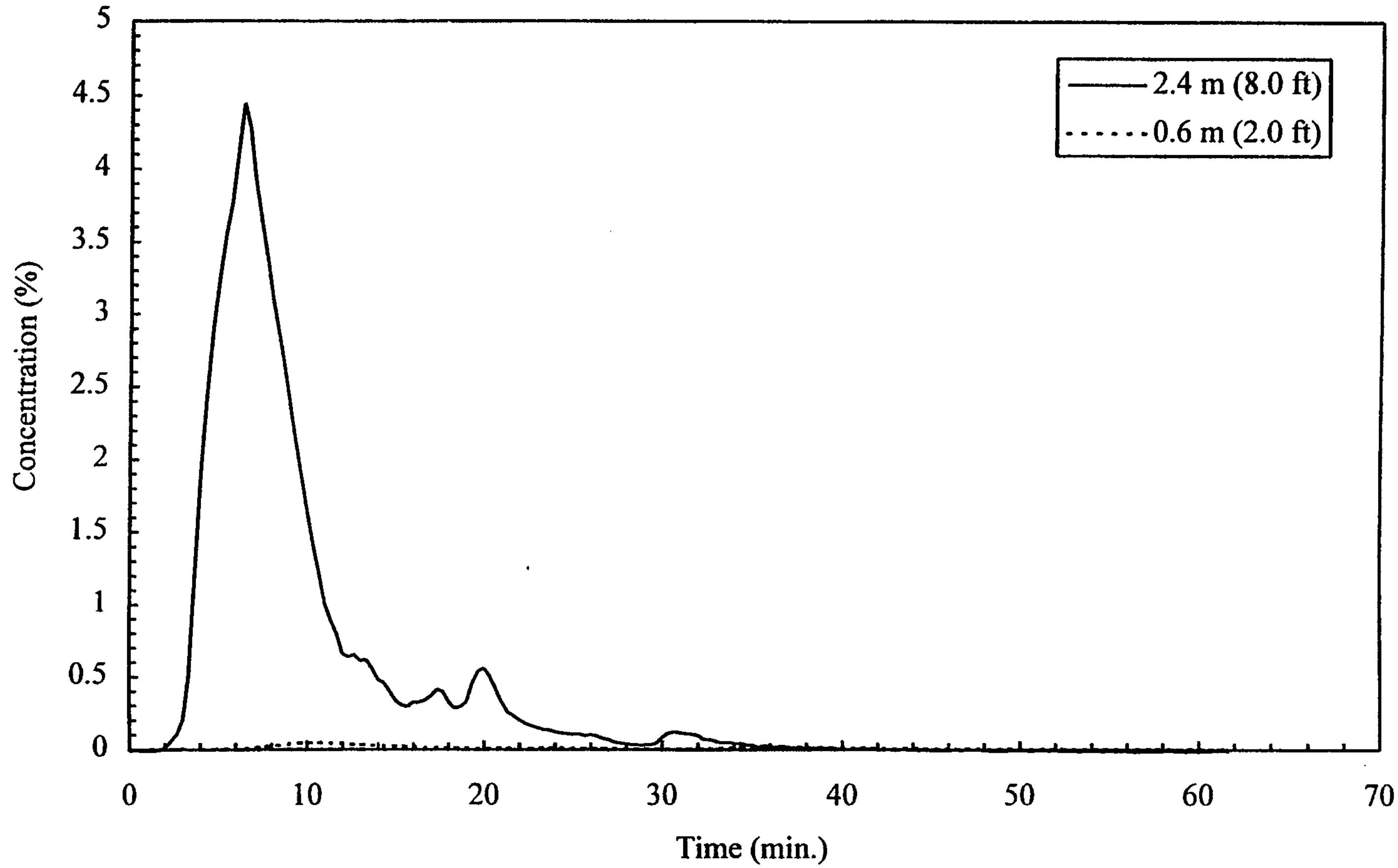

Fig. A8 - Carbon monoxide concentration in GSK

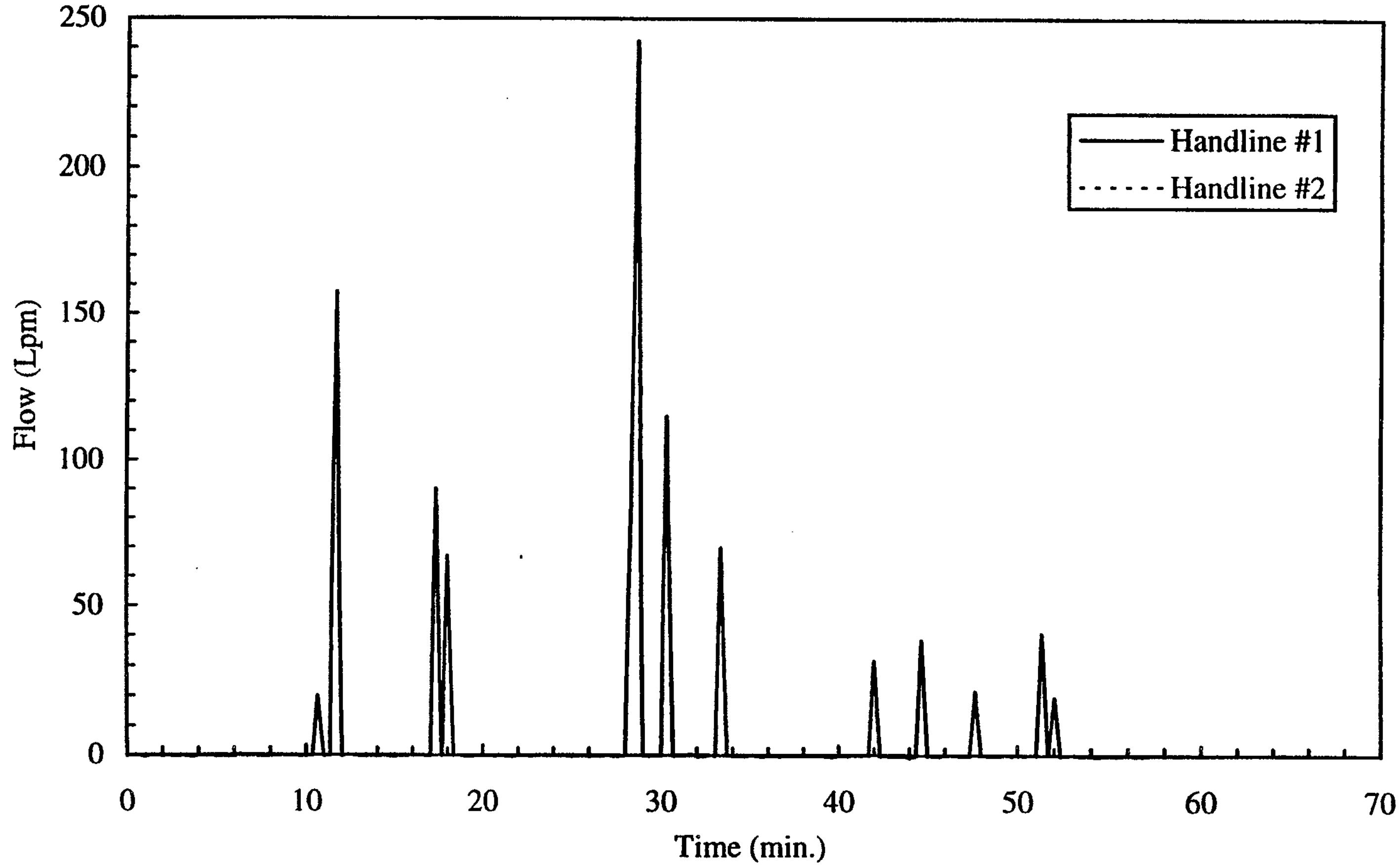

Fig. A9 - Second deck handline flows

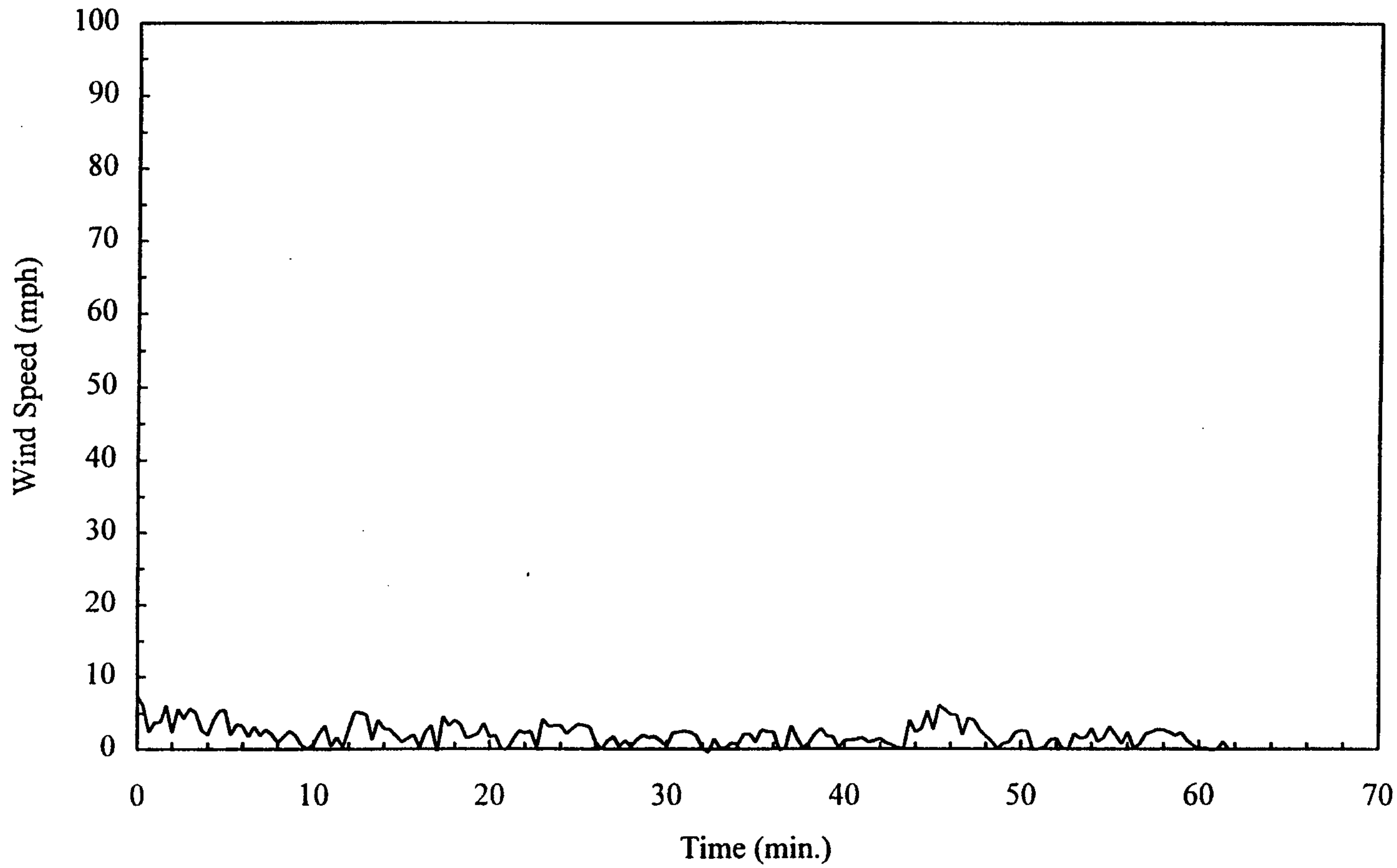

Fig. A10 - Wind speed measured on the flight deck

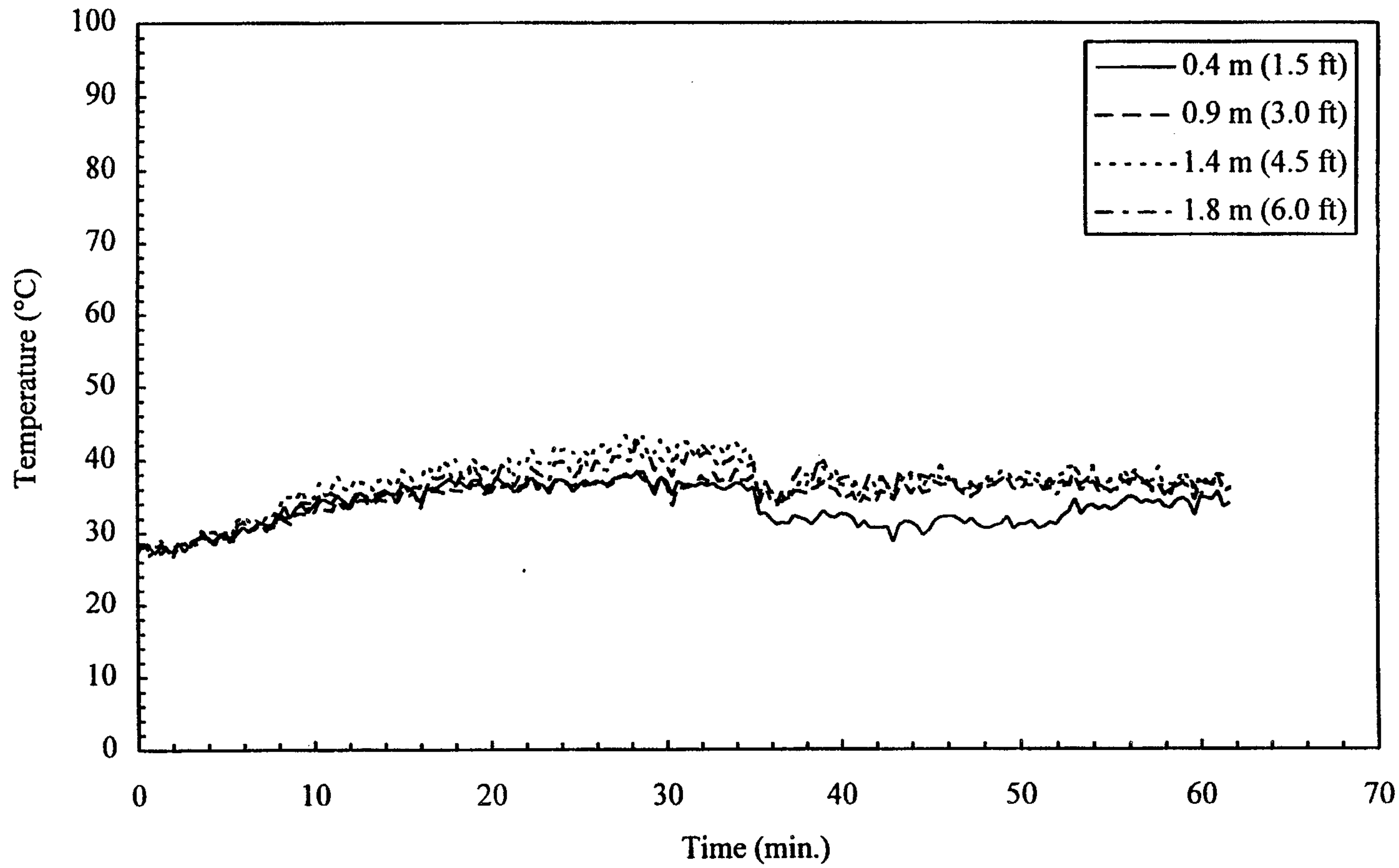

Fig. A11 - Air temperatures measured at 3-19-2

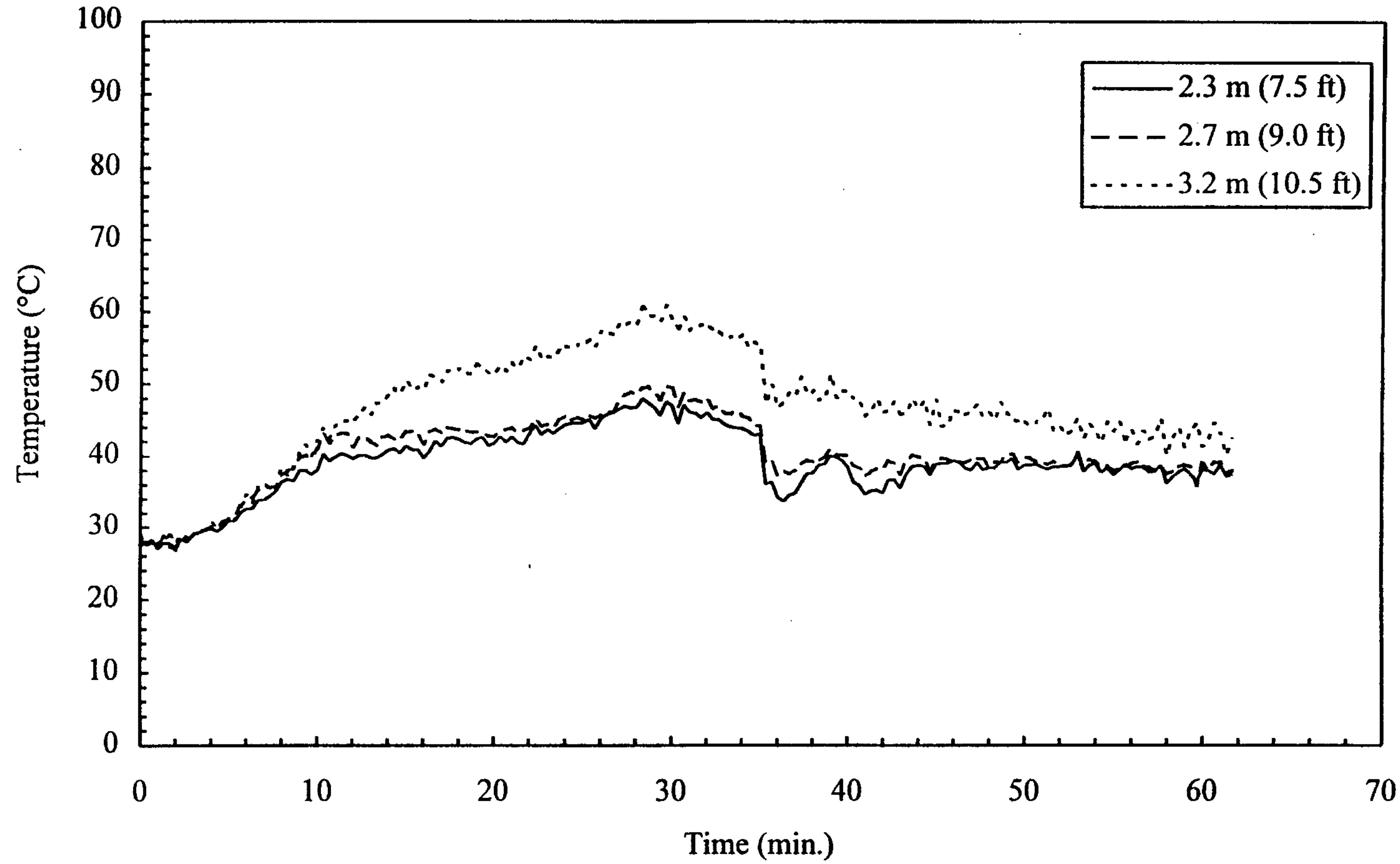

Fig. A12 - Air temperatures measured at 3-19-2

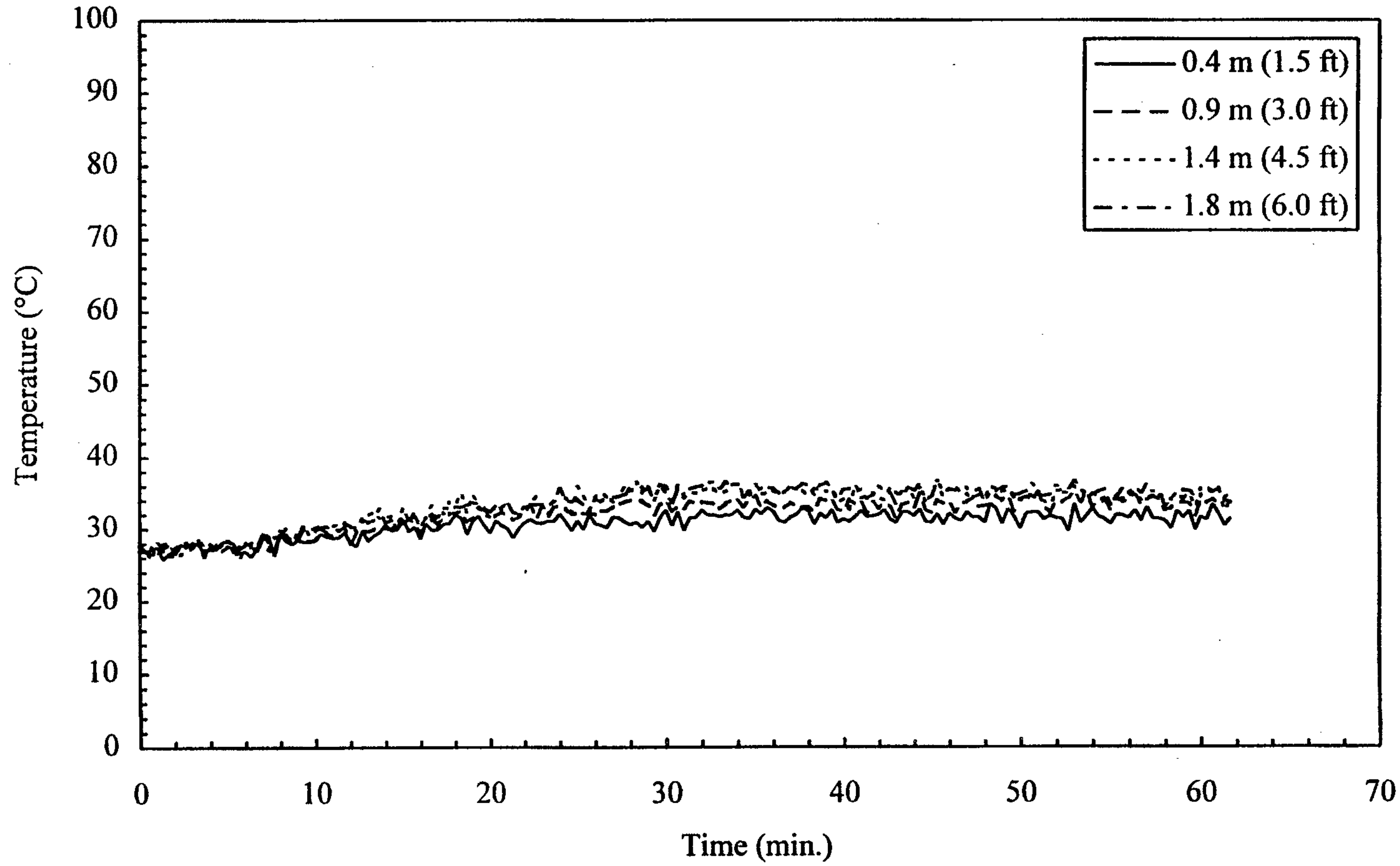

Fig. A13 - Air temperatures measured at 3-19-1

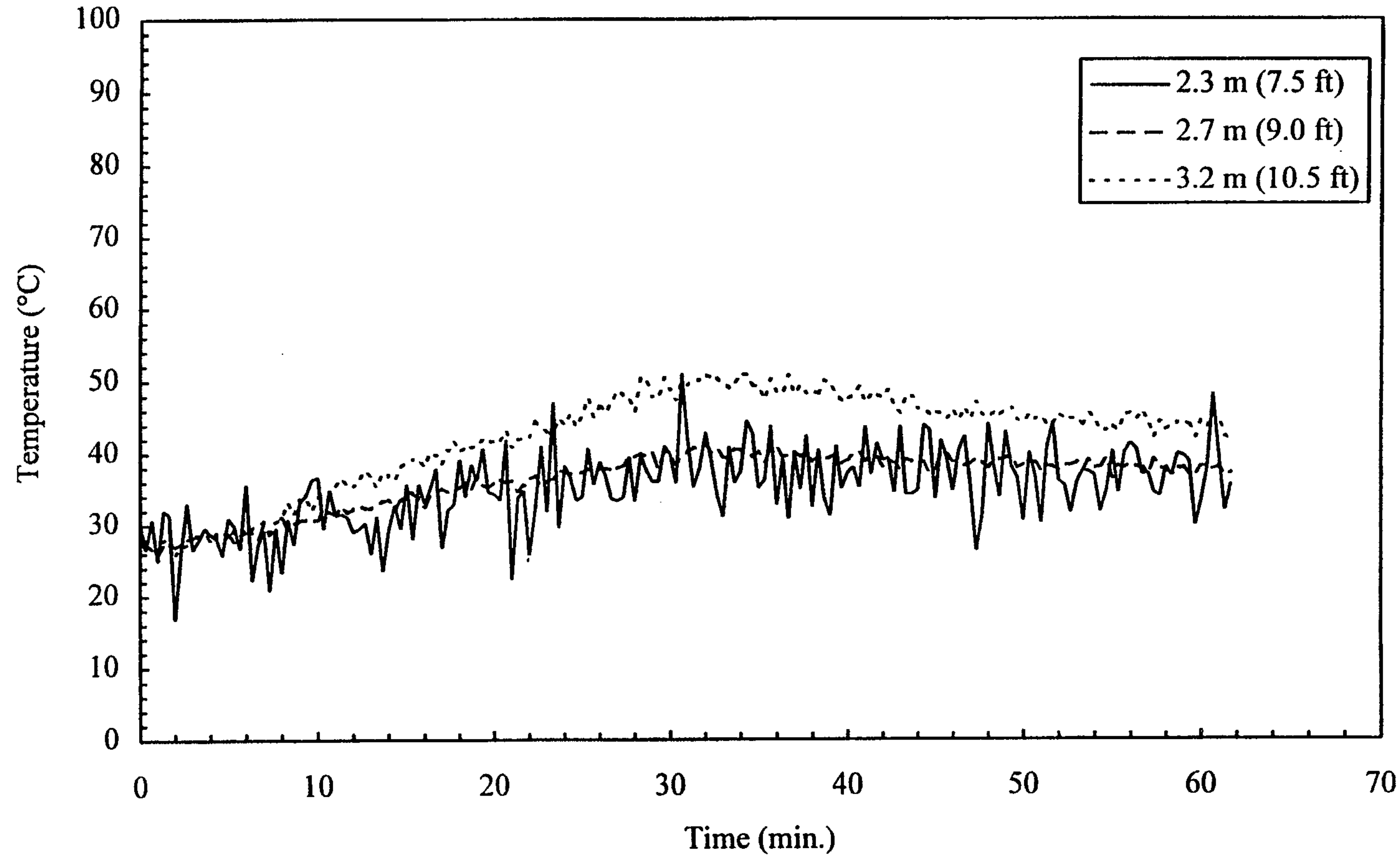

Fig. A14 - Air temperatures measured at 3-19-1

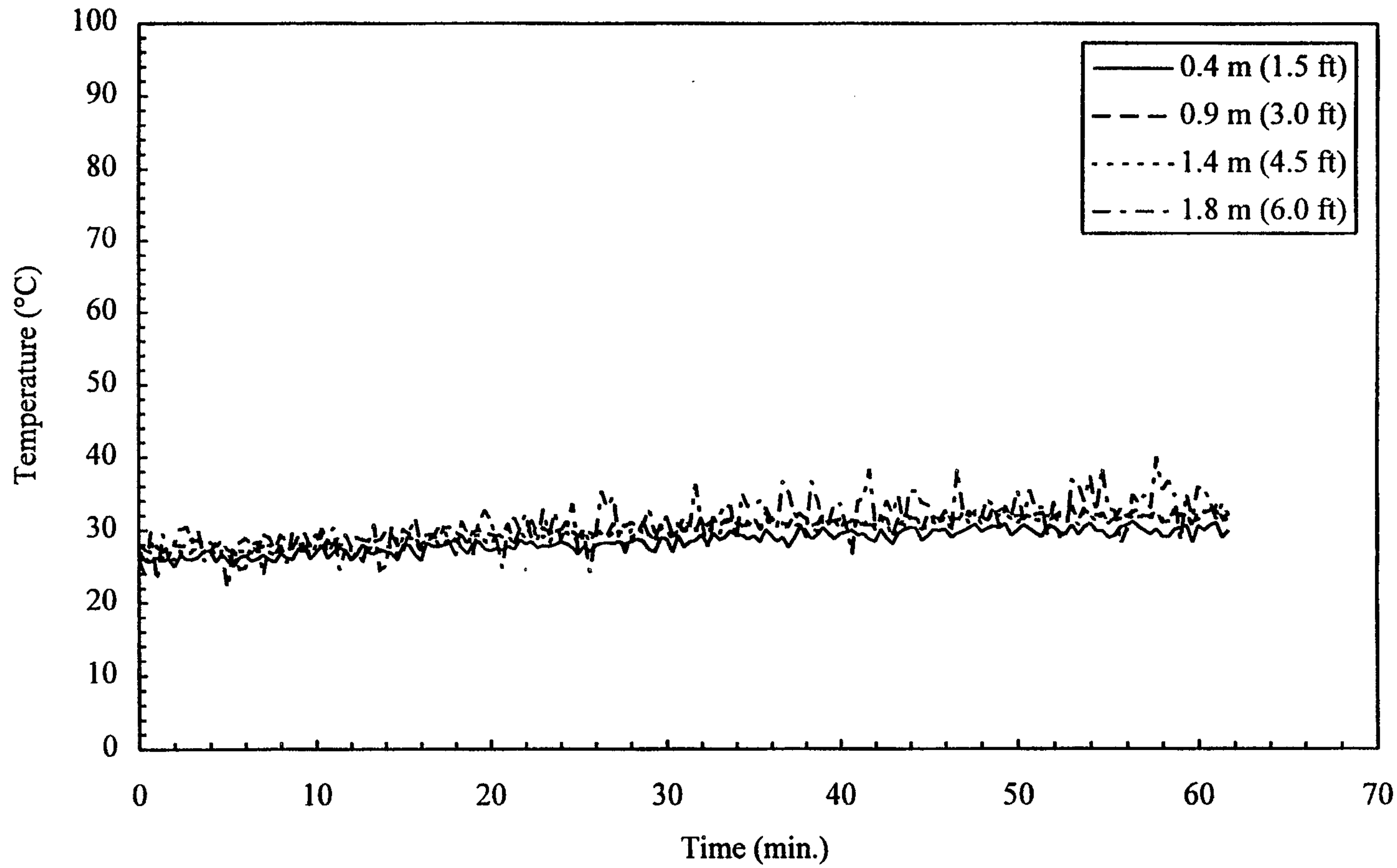

Fig. A15 - Air temperatures measured at 3-16-4

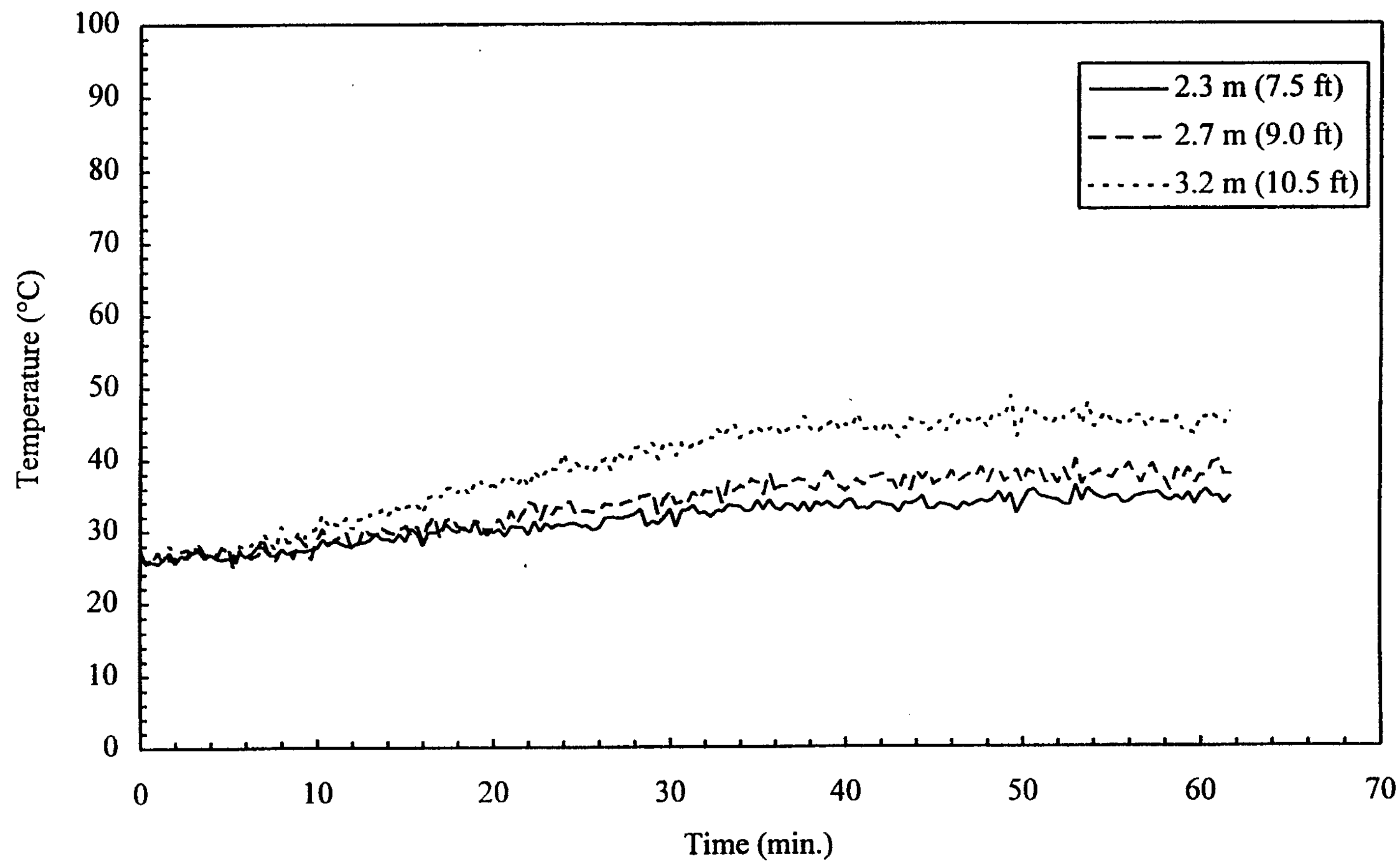

Fig. A16 - Air temperatures measured at 3-16-4

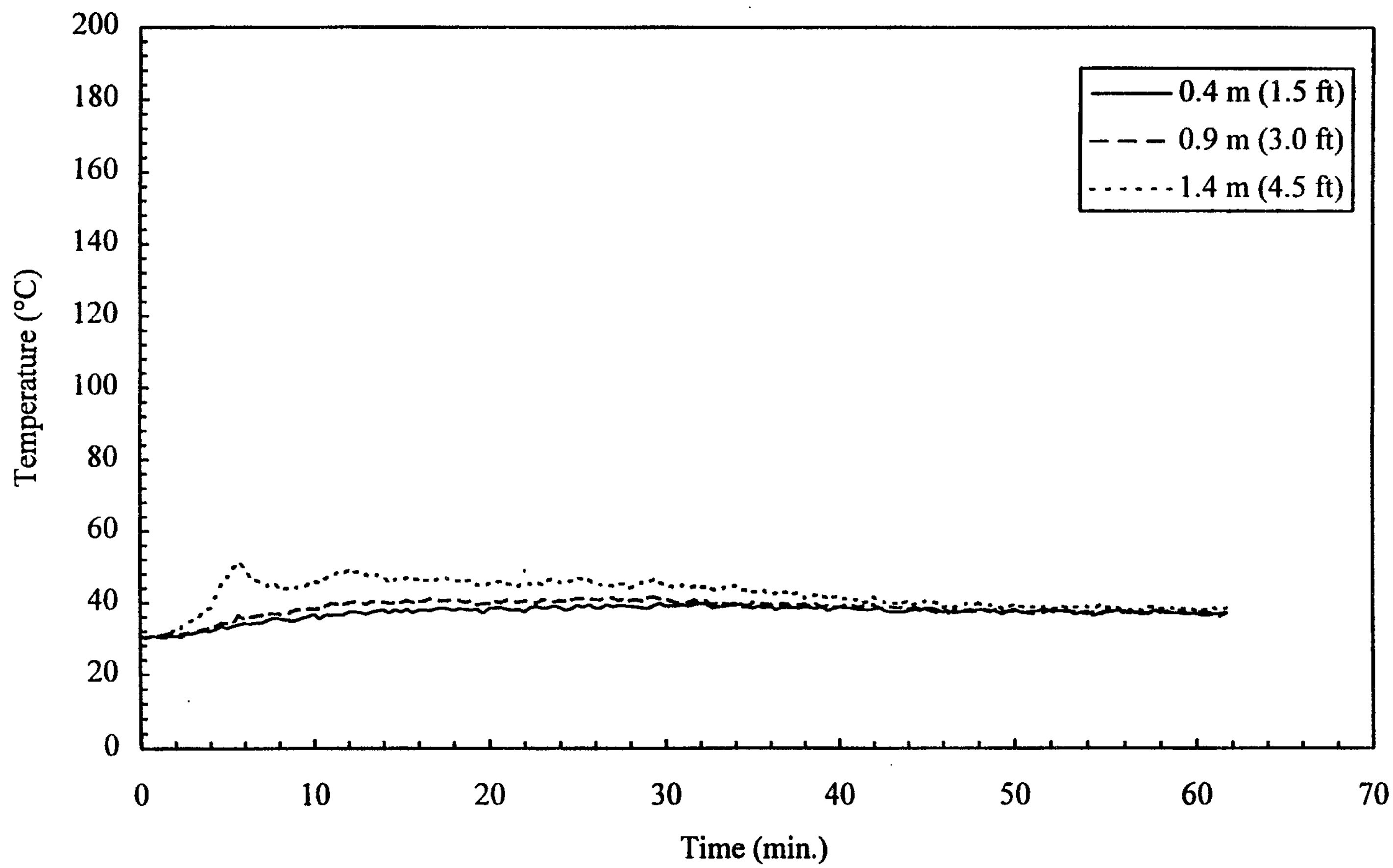

Fig. A17 - Air temperatures measured at 2-21-1

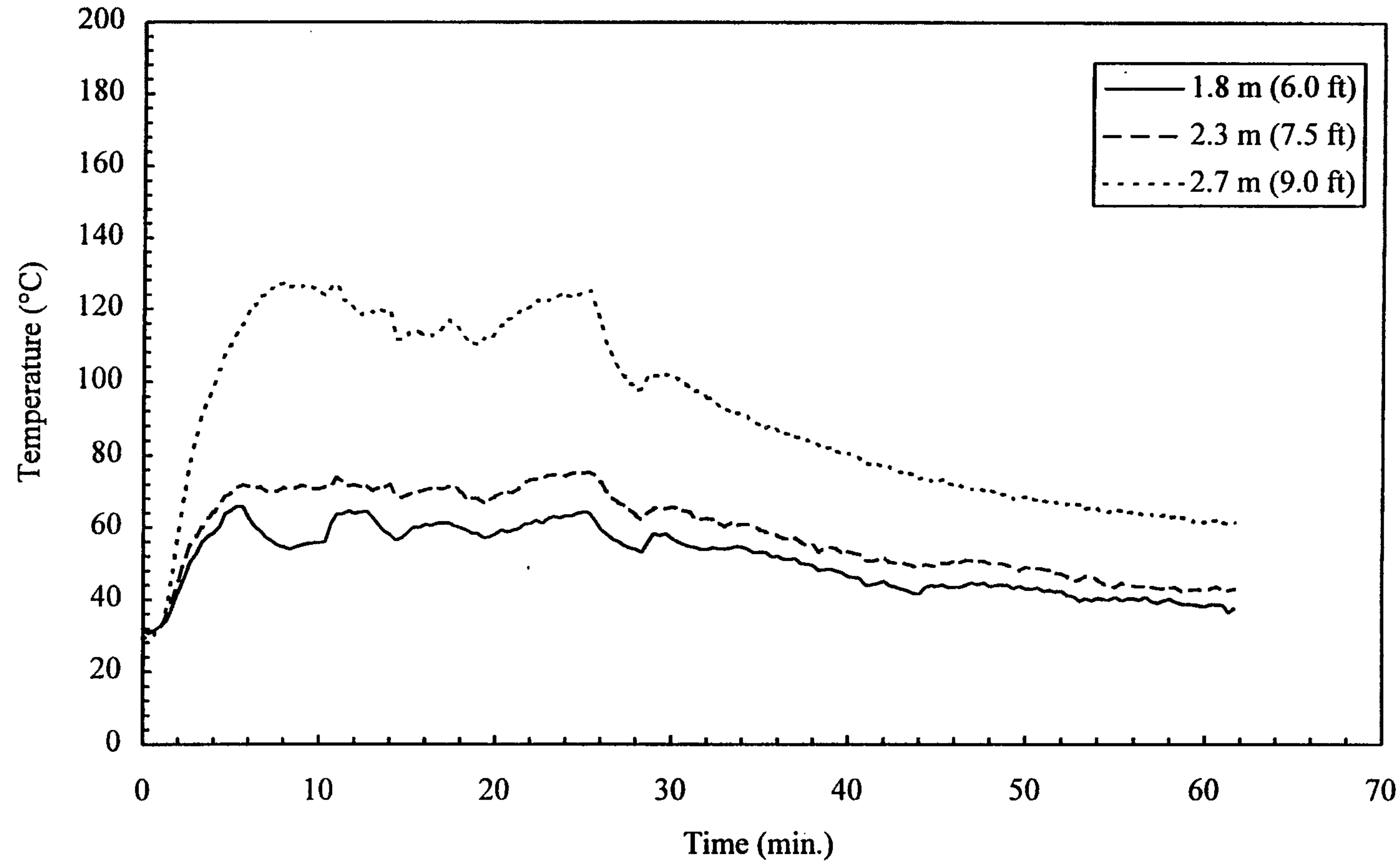

Fig. A18 - Air temperatures measured at 2-21-1

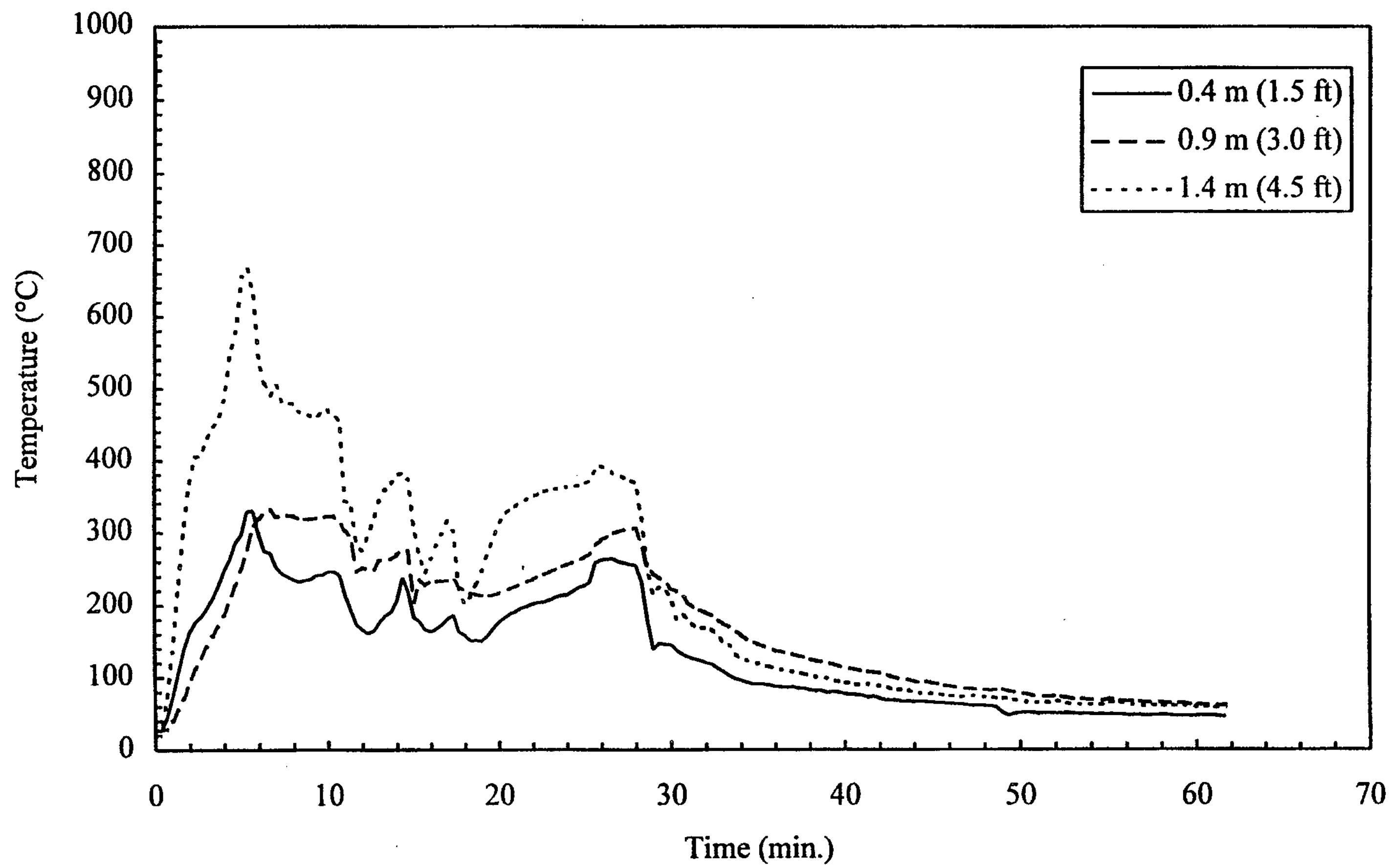

Fig. A19 - Air temperatures measured at 2-19-0

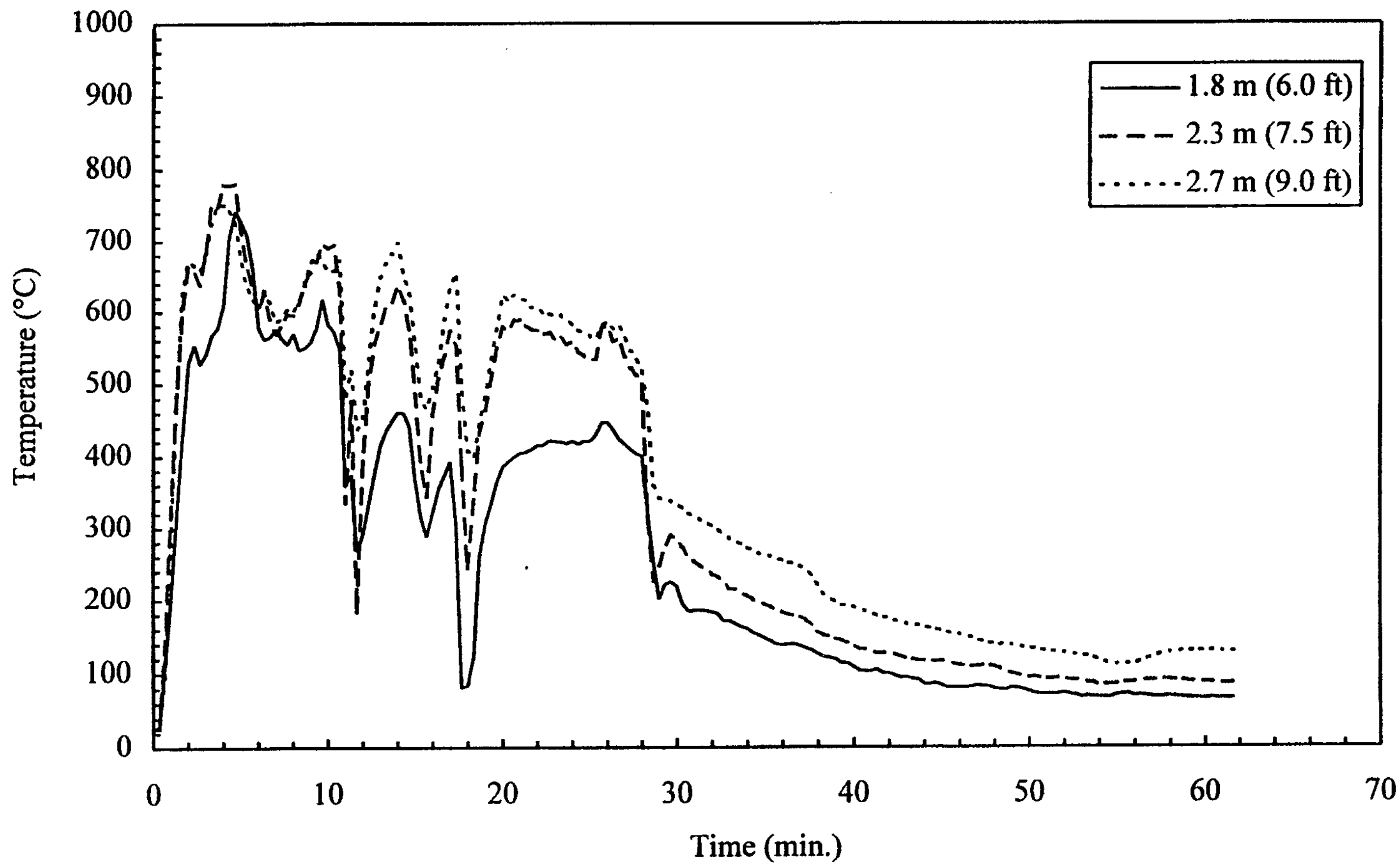

Fig. A20 - Air temperatures measured at 2-19-0

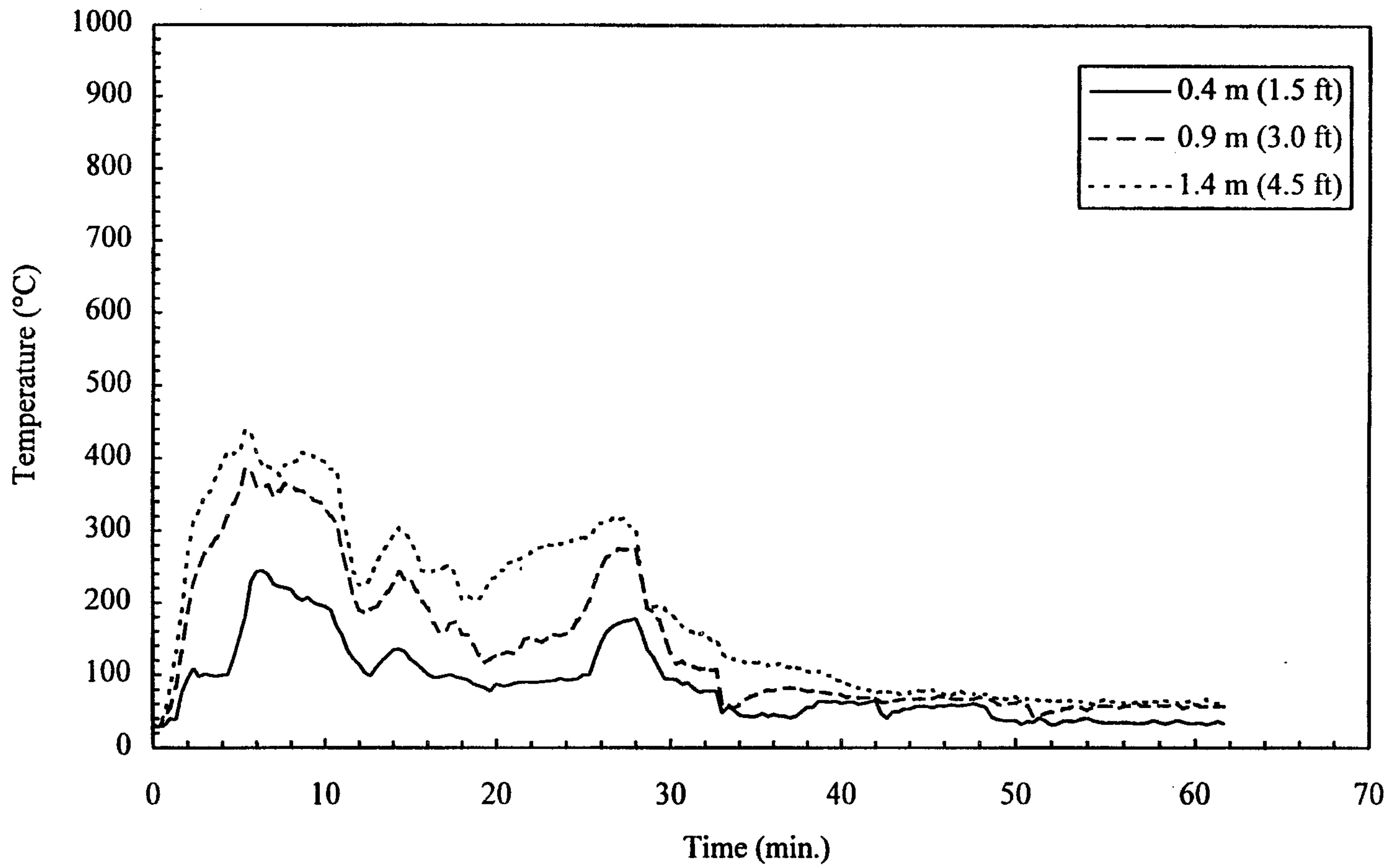

Fig. A21 - Air temperatures measured at 2-18-2

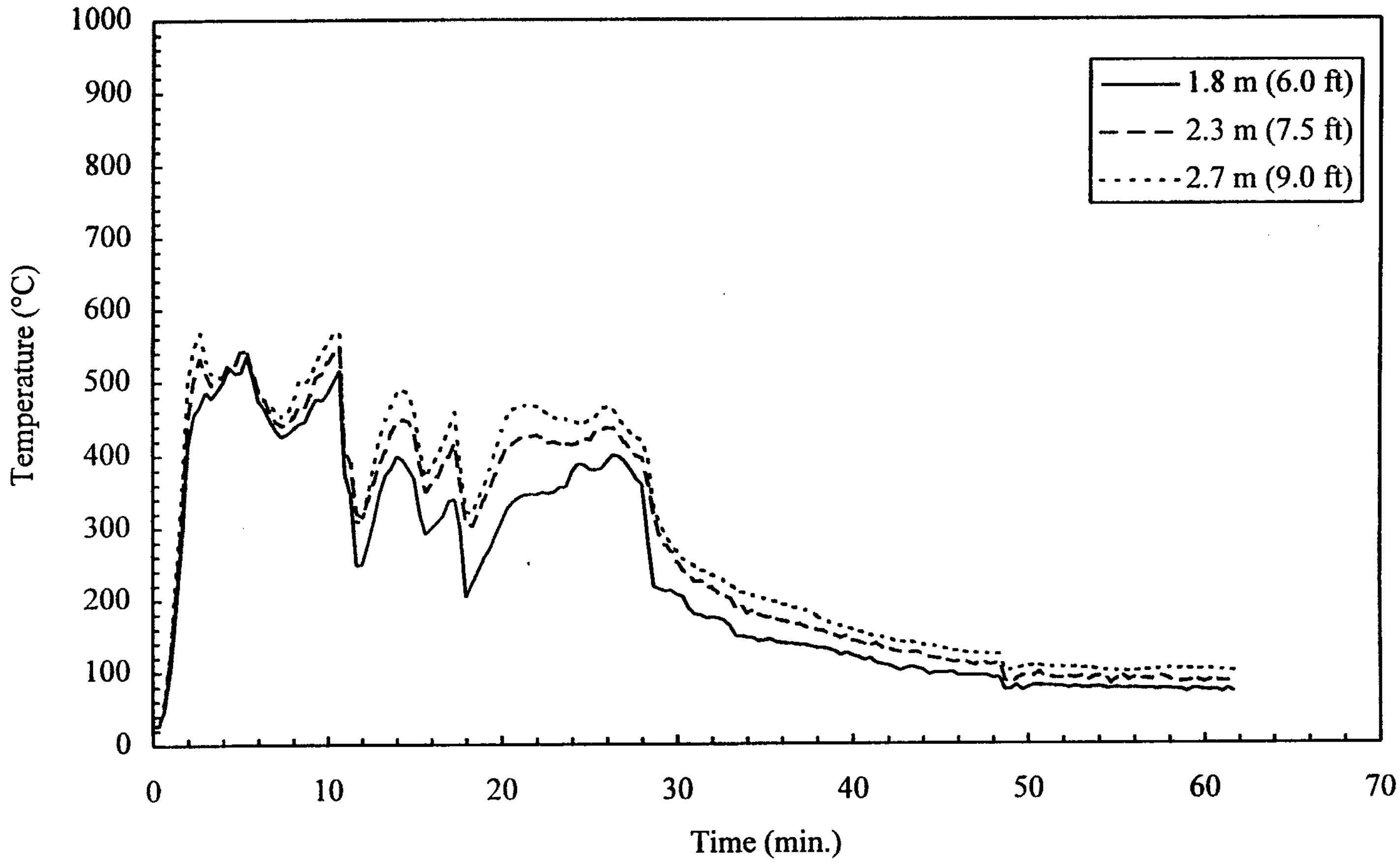

Fig. A22 - Air temperatures measured at 2-18-2

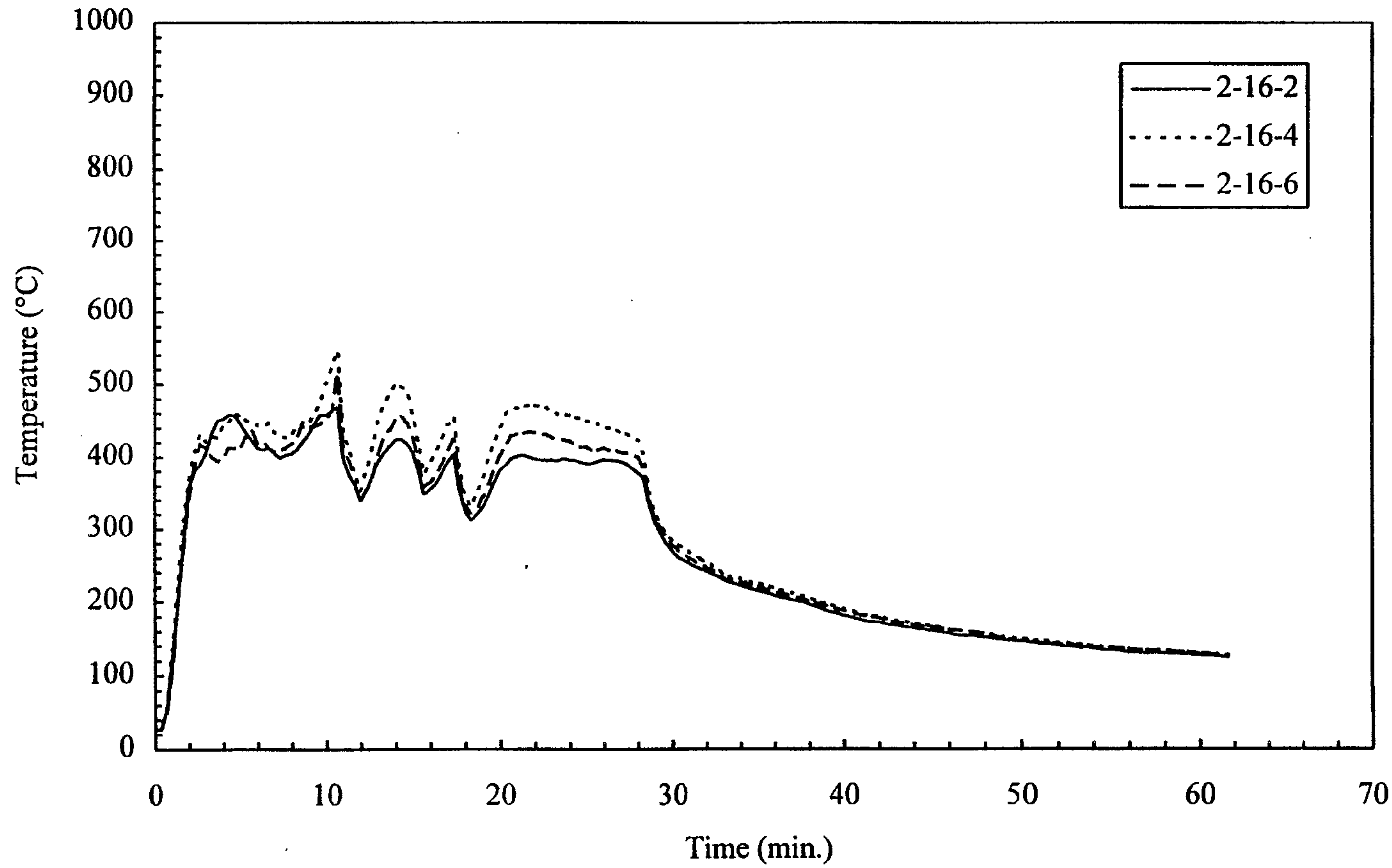

Fig. A23 - Overhead temperatures measured at FR 16 in Storage

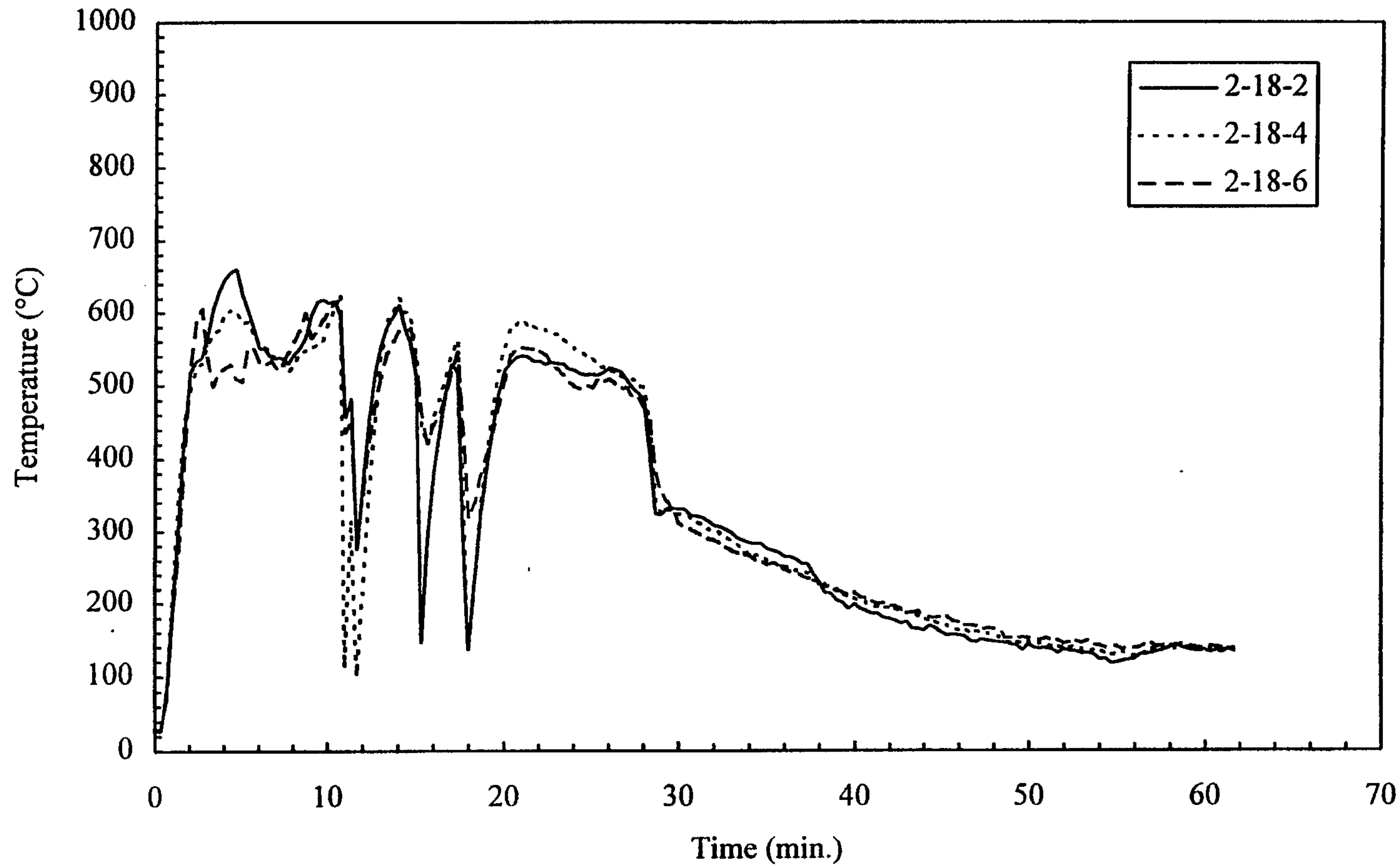

Fig. A24 - Overhead temperatures measured at FR 18 in Storage

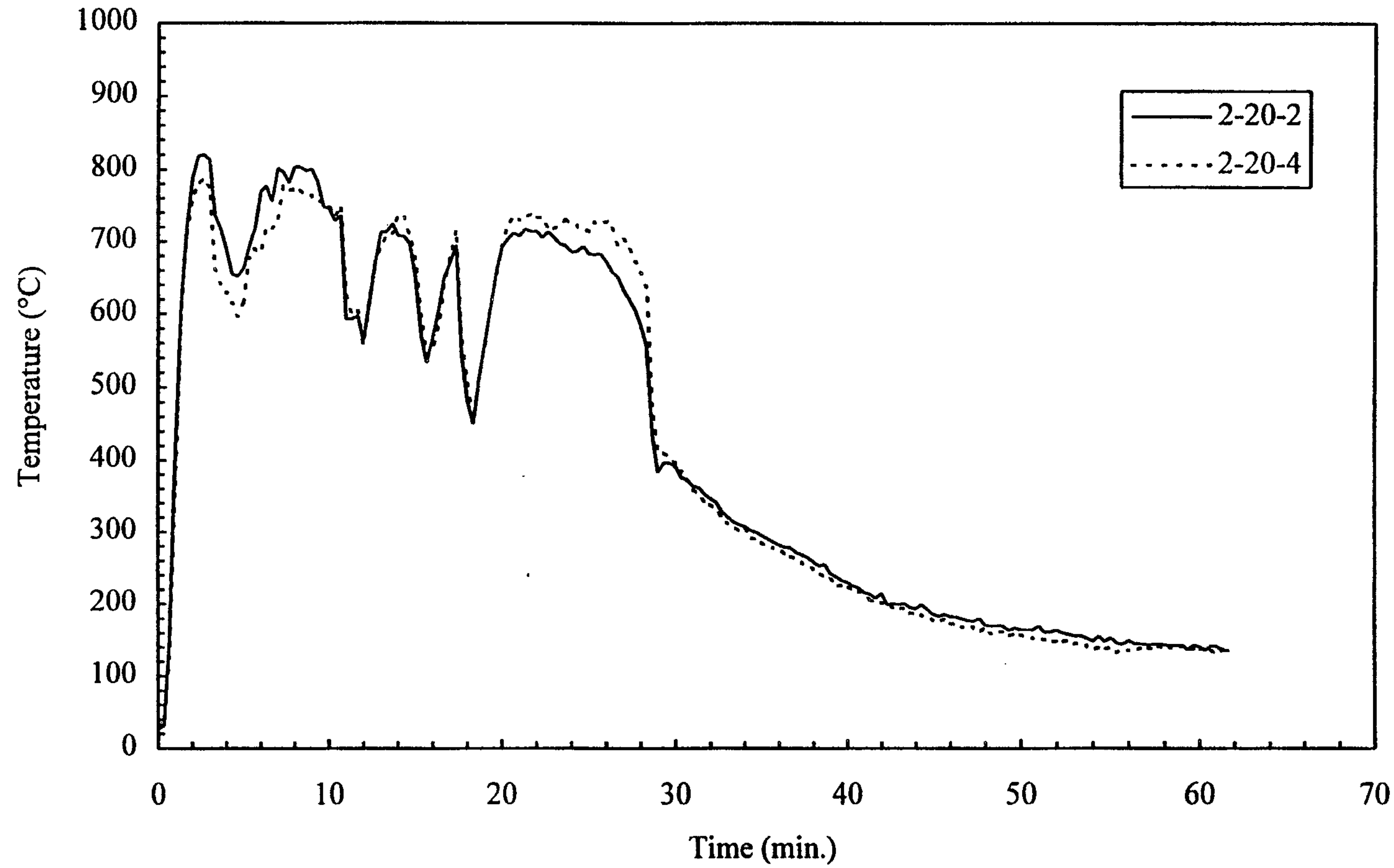

Fig. A25 - Overhead temperatures measured at FR 20 in Storage

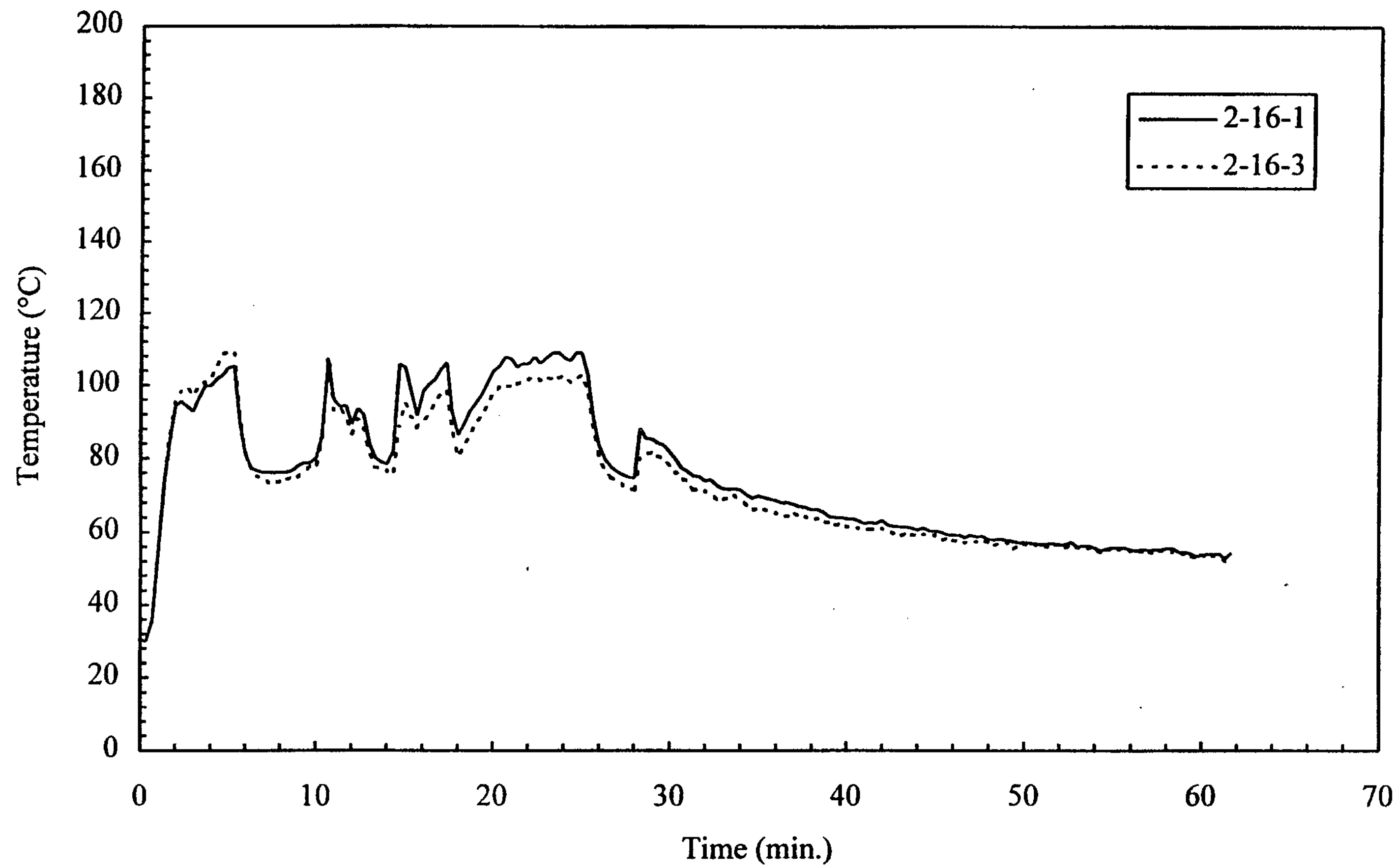

Fig. A26 - Overhead temperatures measured at FR 16 in GSK

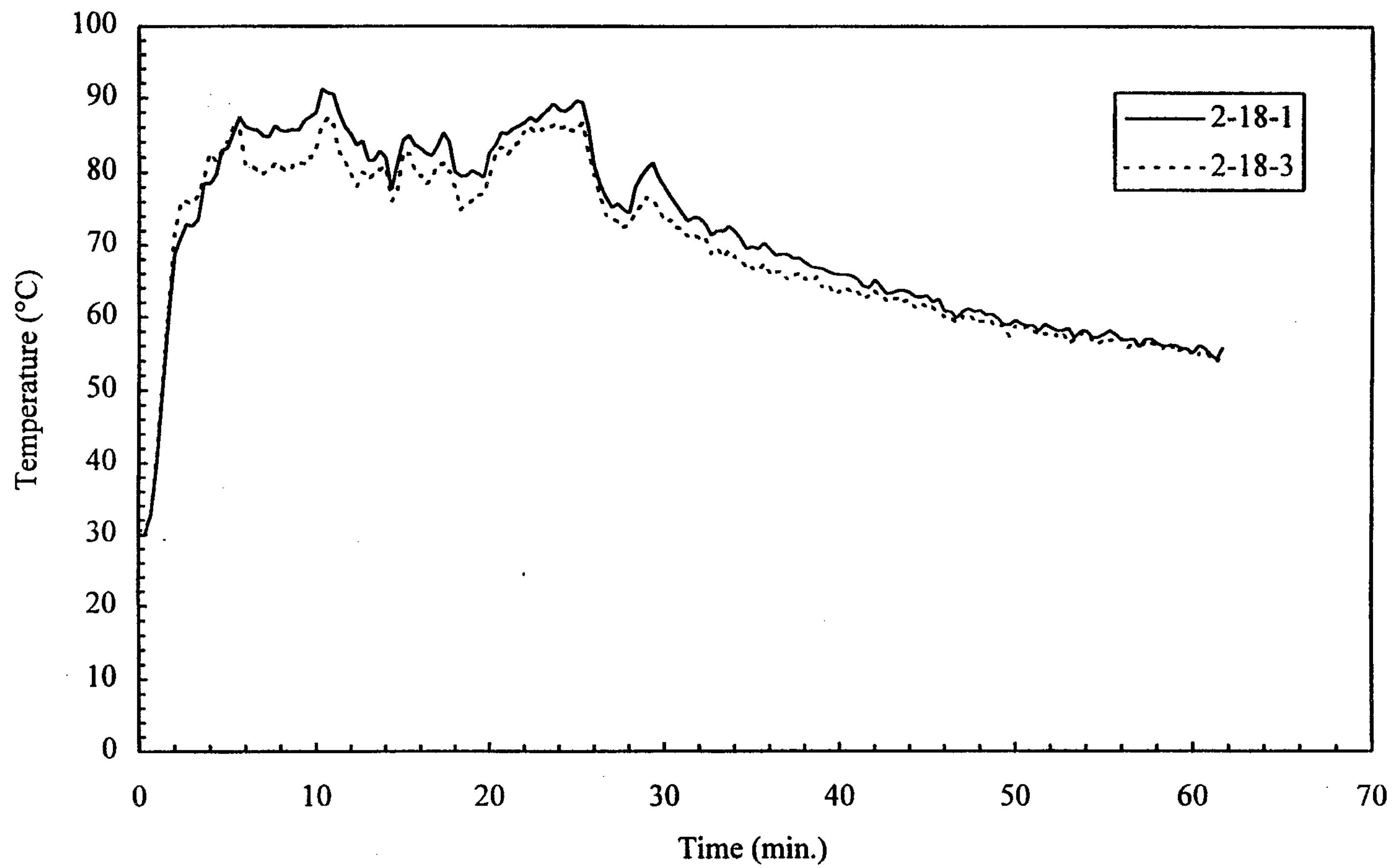

Fig. A27 - Overhead temperatures measured at FR 18 in GSK

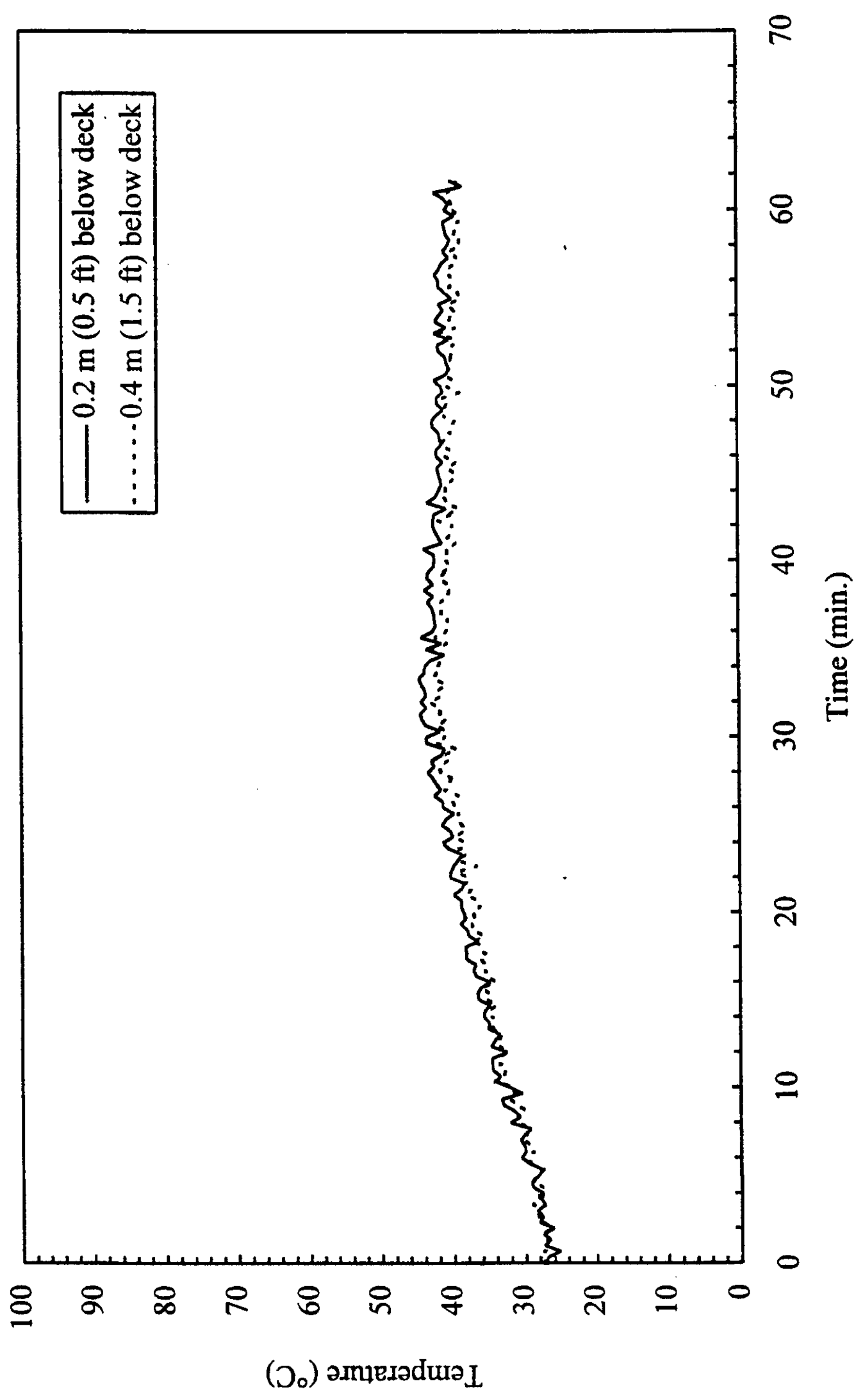

Fig. A28 - Overhead temperatures measured at 3-17-1

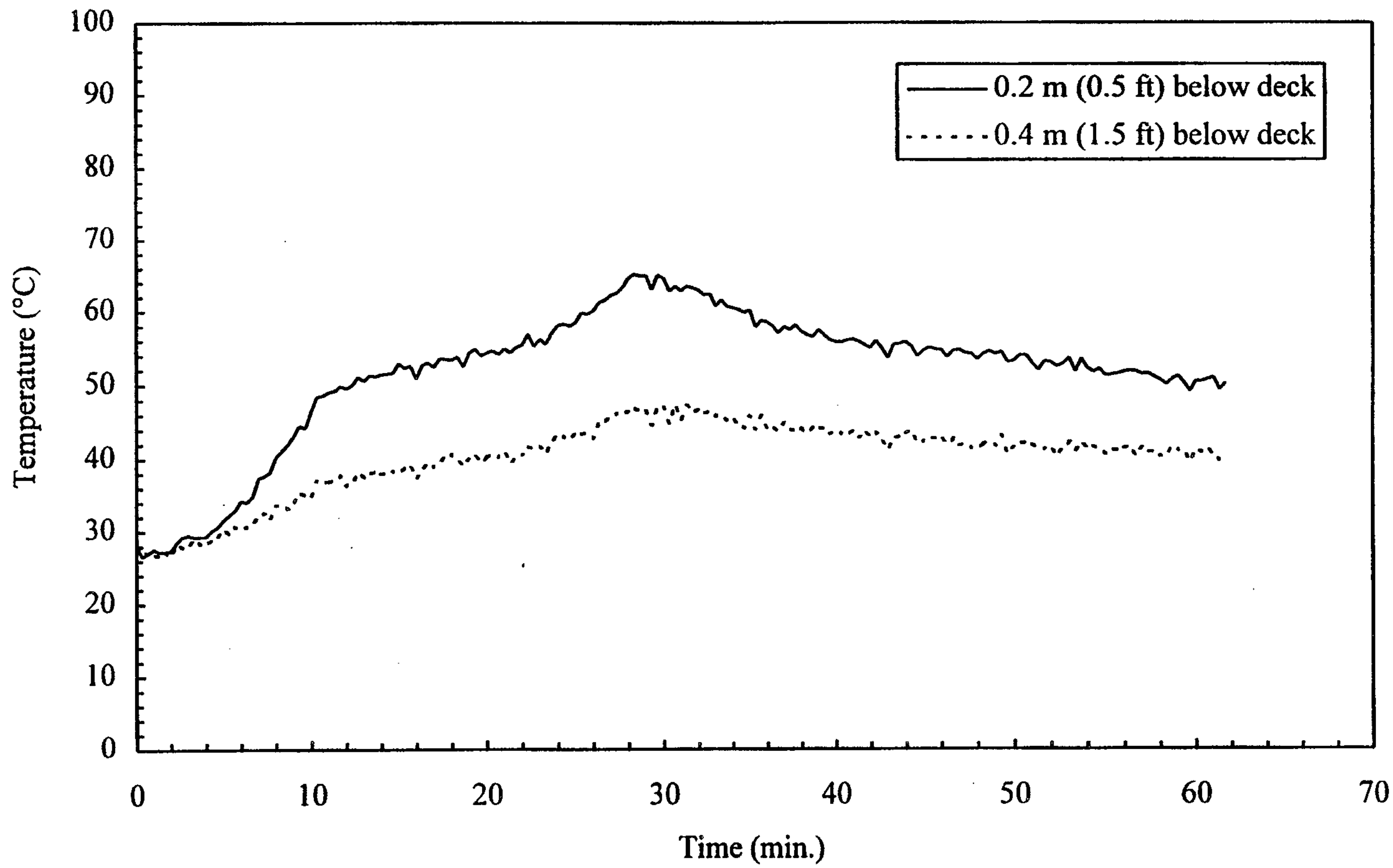

Fig. A29 - Overhead temperatures measured at 3-17-2

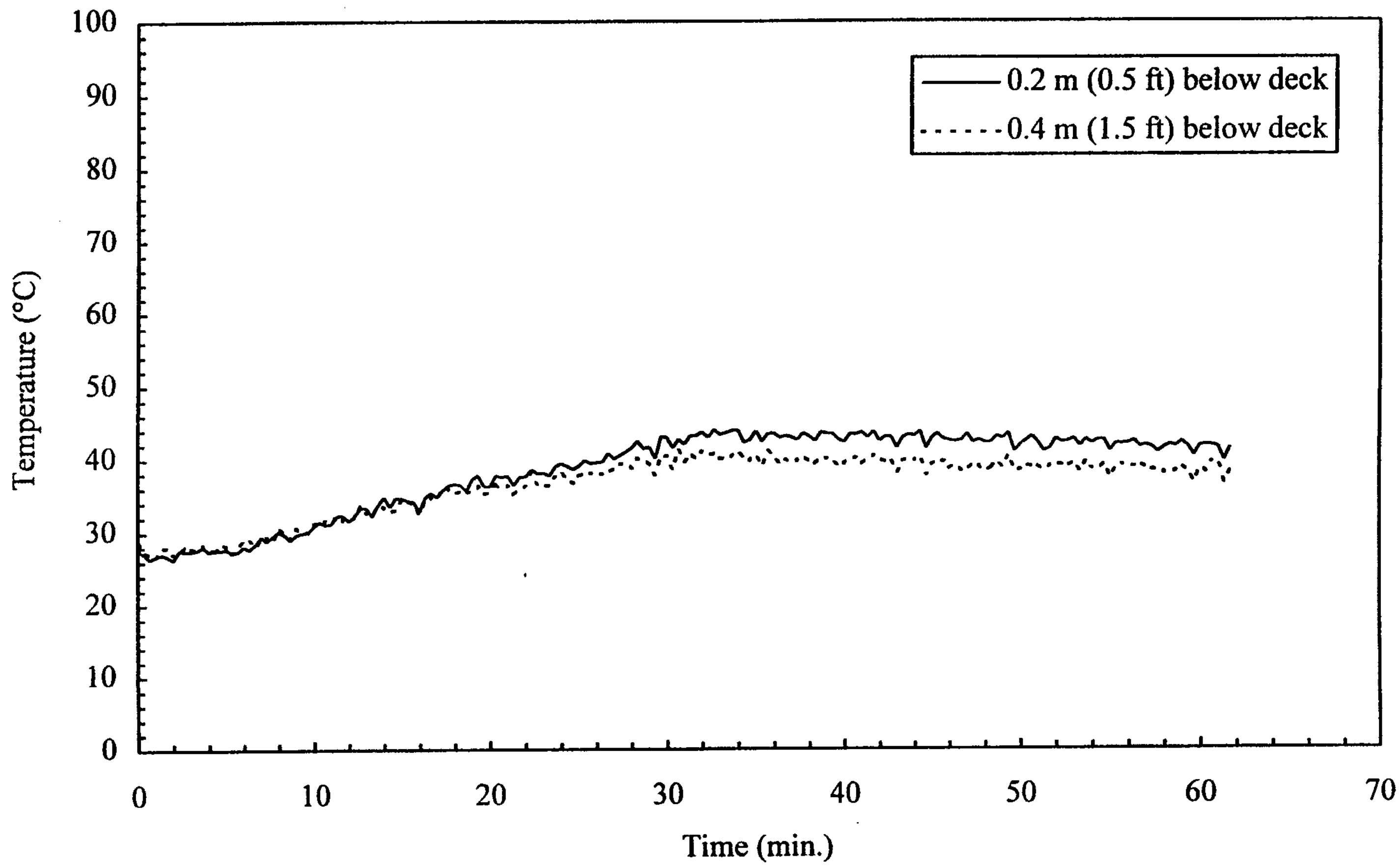

Fig. A30 - Overhead temperatures measured at 3-21-1

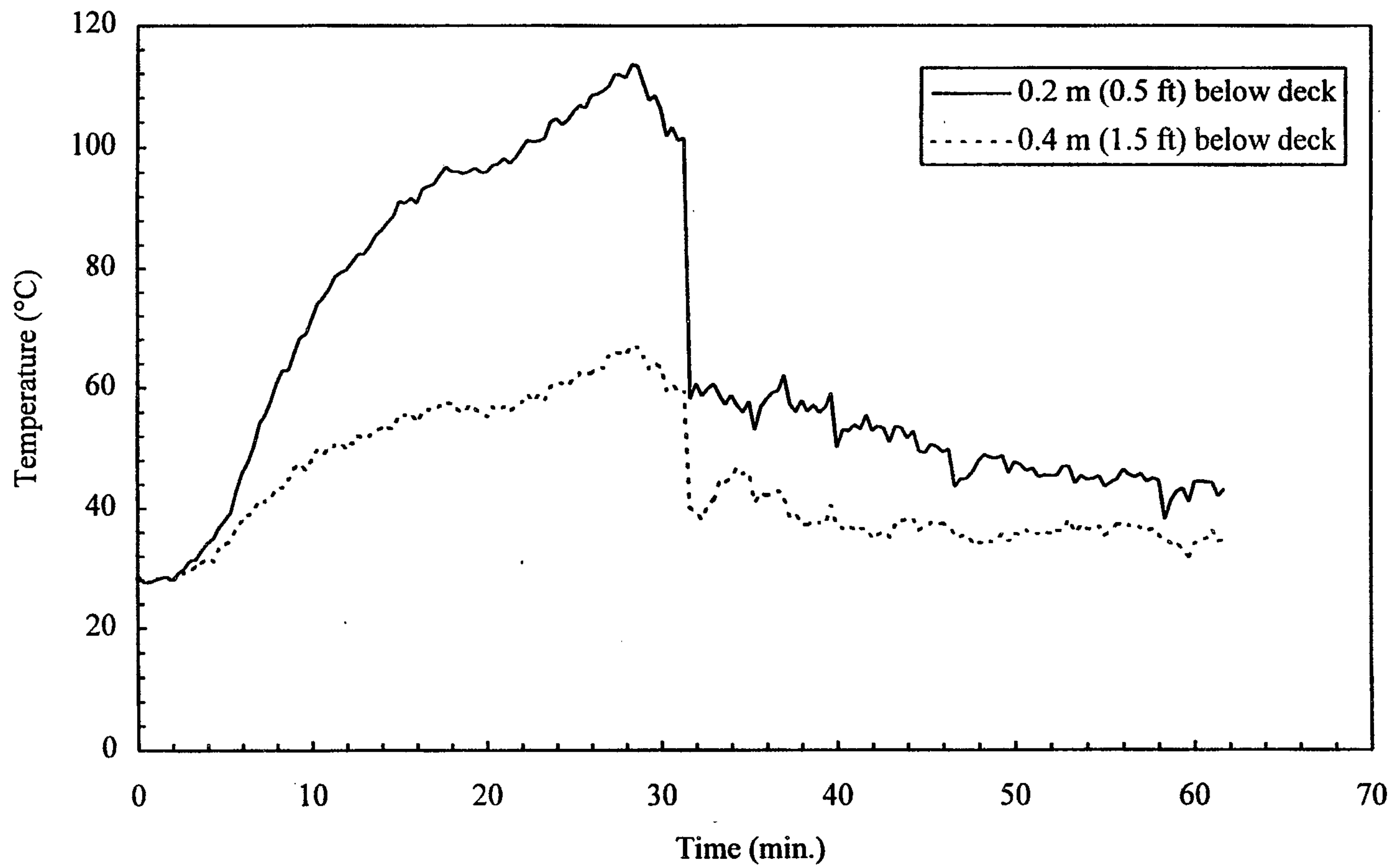

Fig. A31 - Overhead temperatures measured at 3-21-2

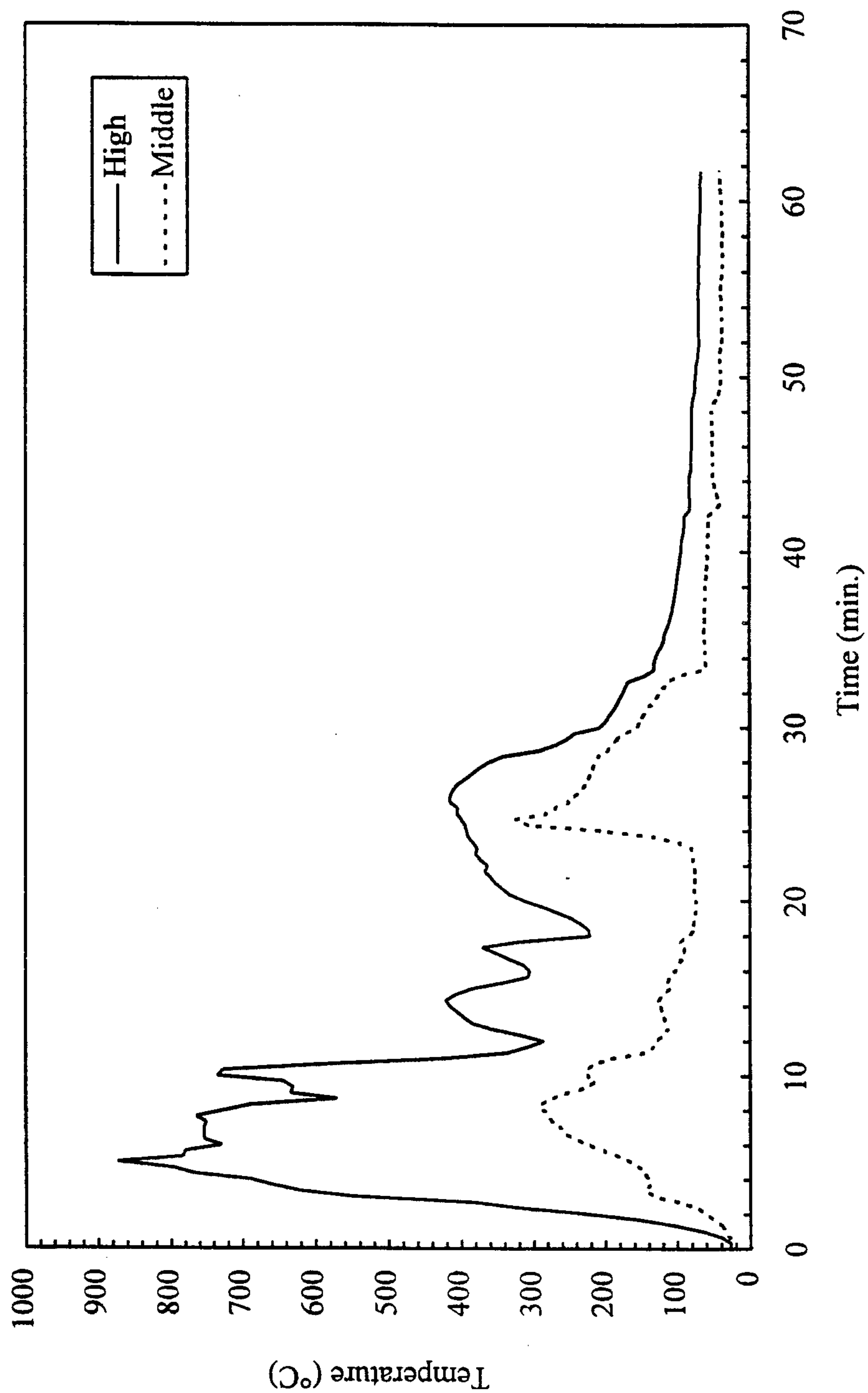

Fig. A32 - Crib 1 temperatures

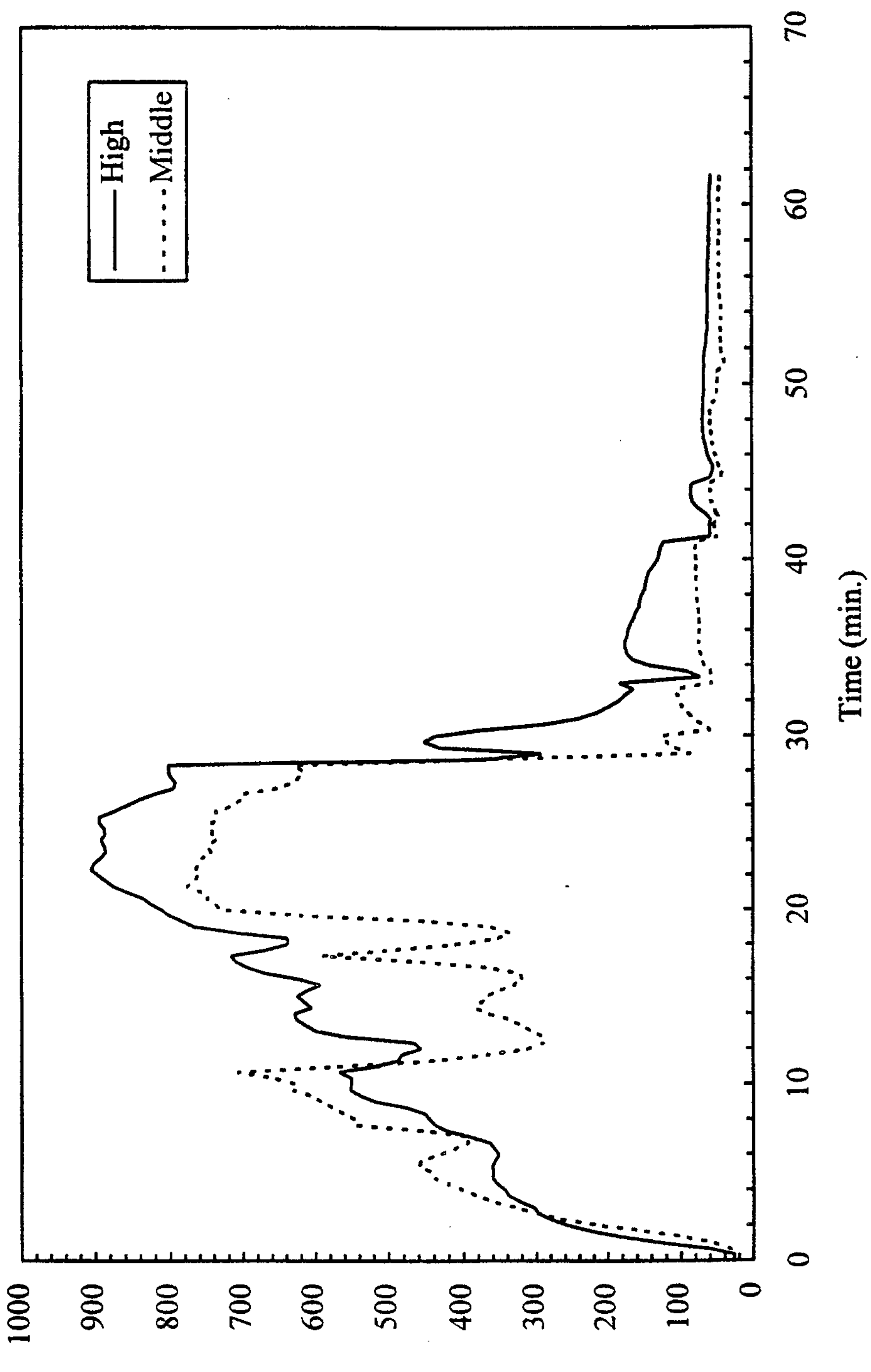

Fig. A33 - Crib 2 temperatures

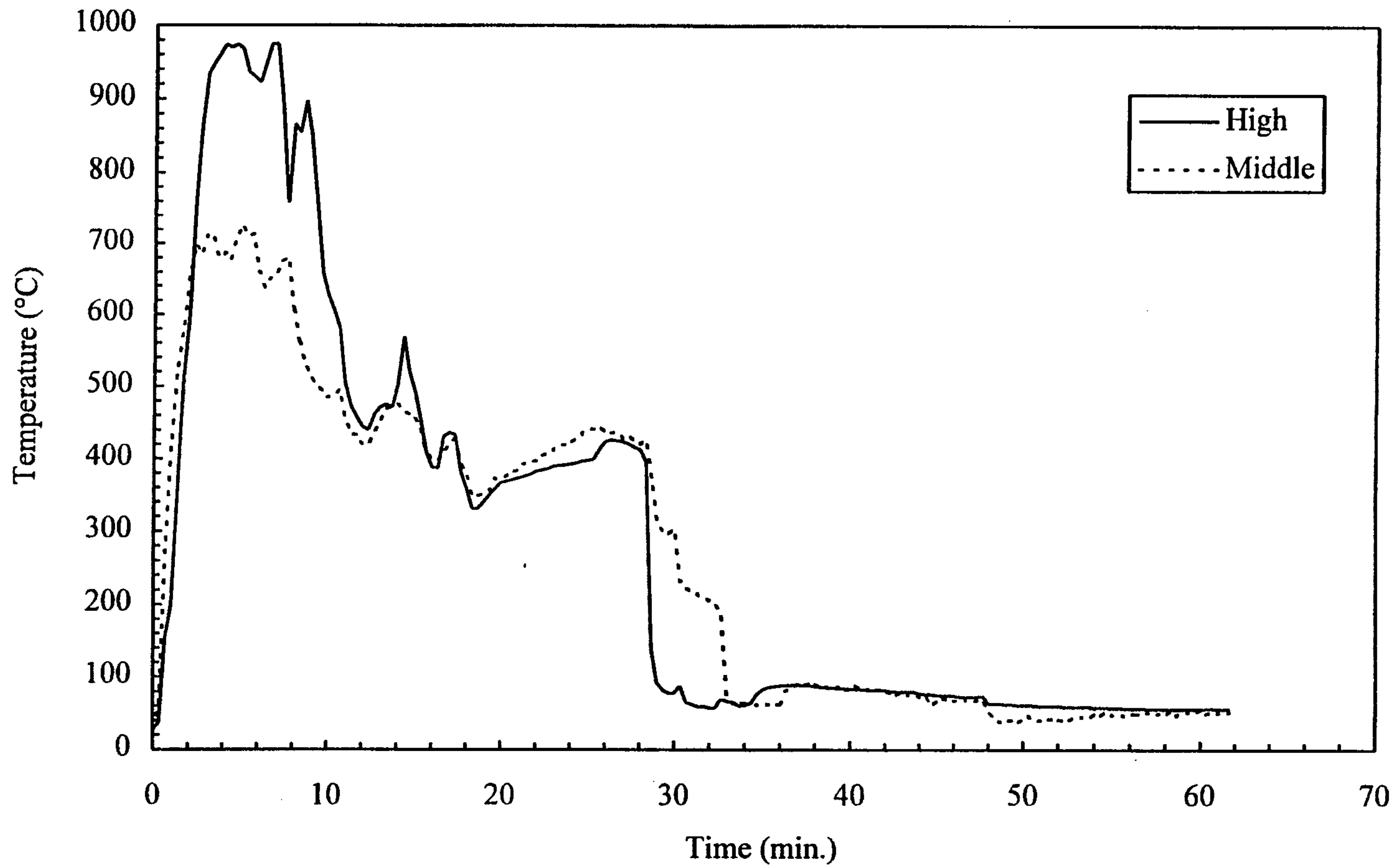

Fig. A34 - Crib 3 temperatures

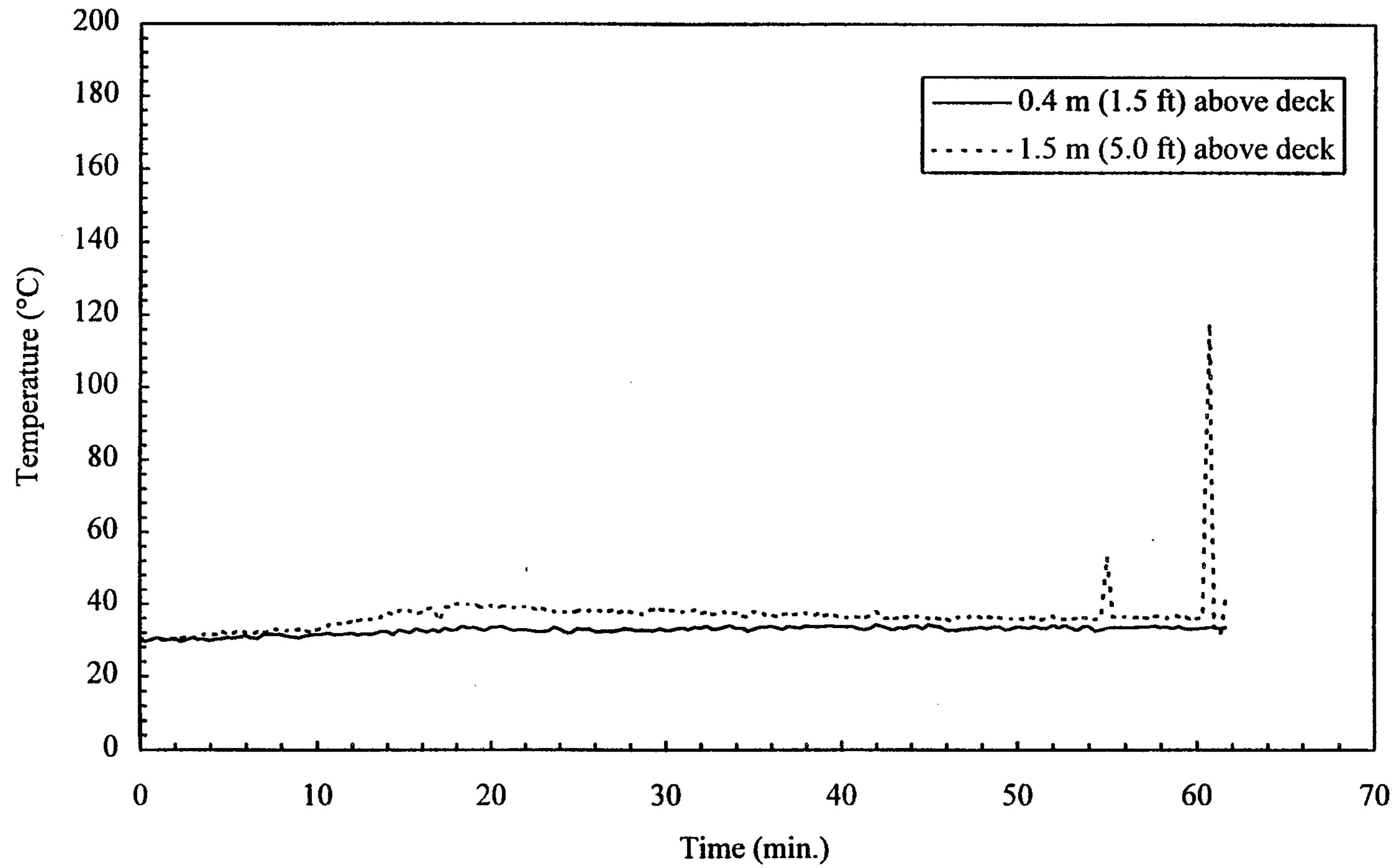

Fig. A35 - Air temperatures measured at FR 18 in the starboard passageway

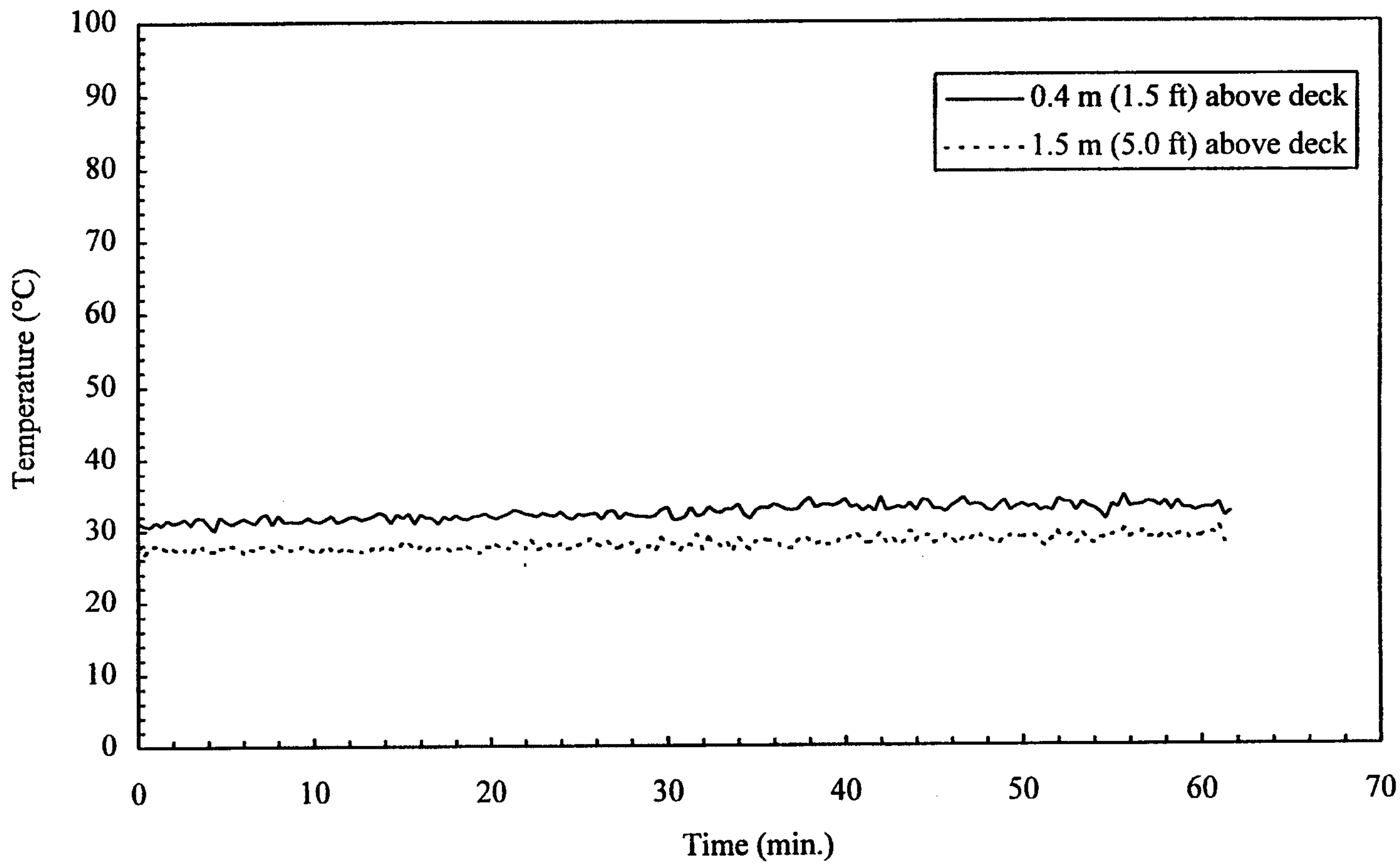

Fig. A36 - Air Temperature in Repair 2 at 2-9-1

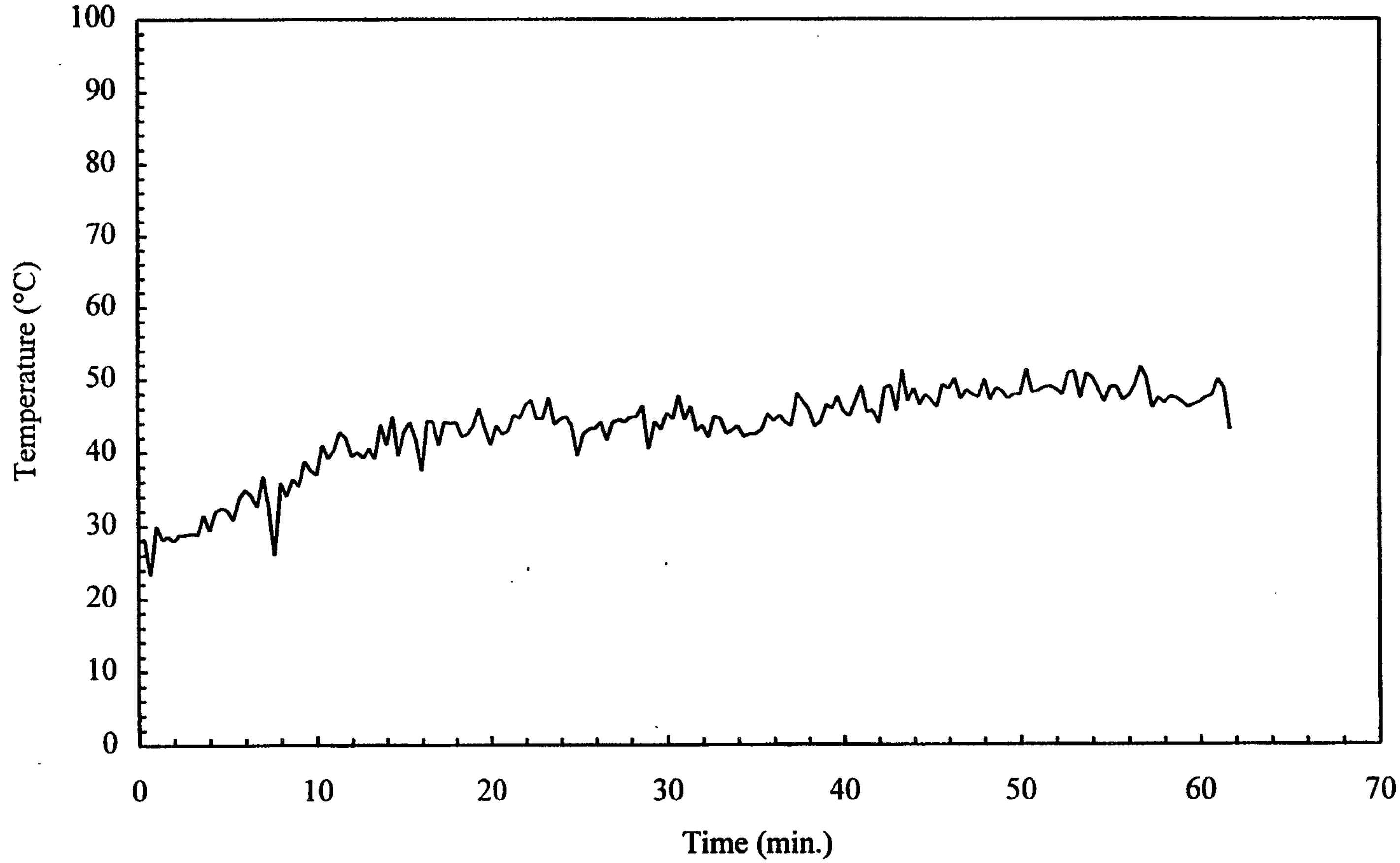

Fig. A37 - Overhead deck temperature measured at 3-17-1

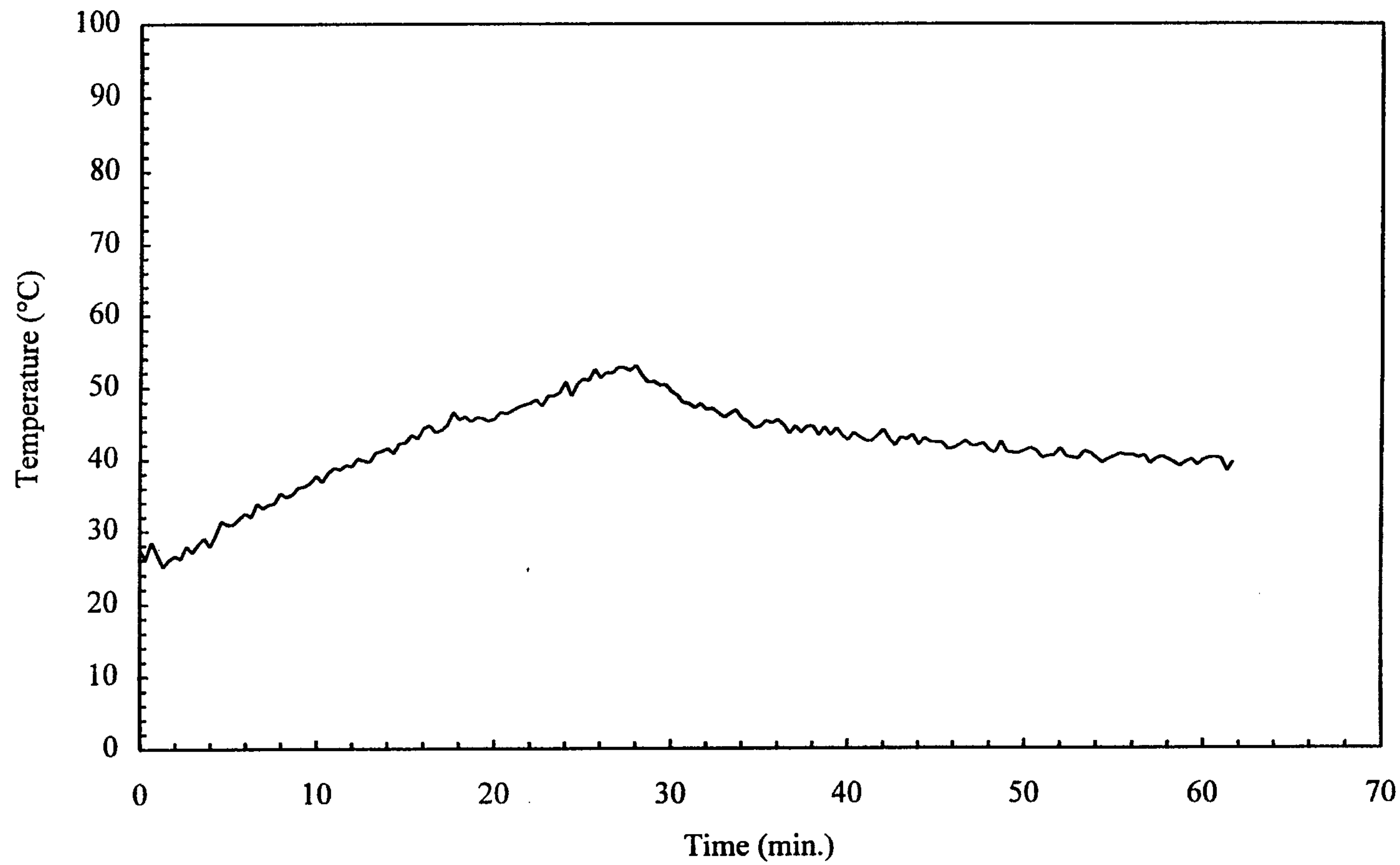

Fig. A38 - Deck temperature in GSK at 2-18-0

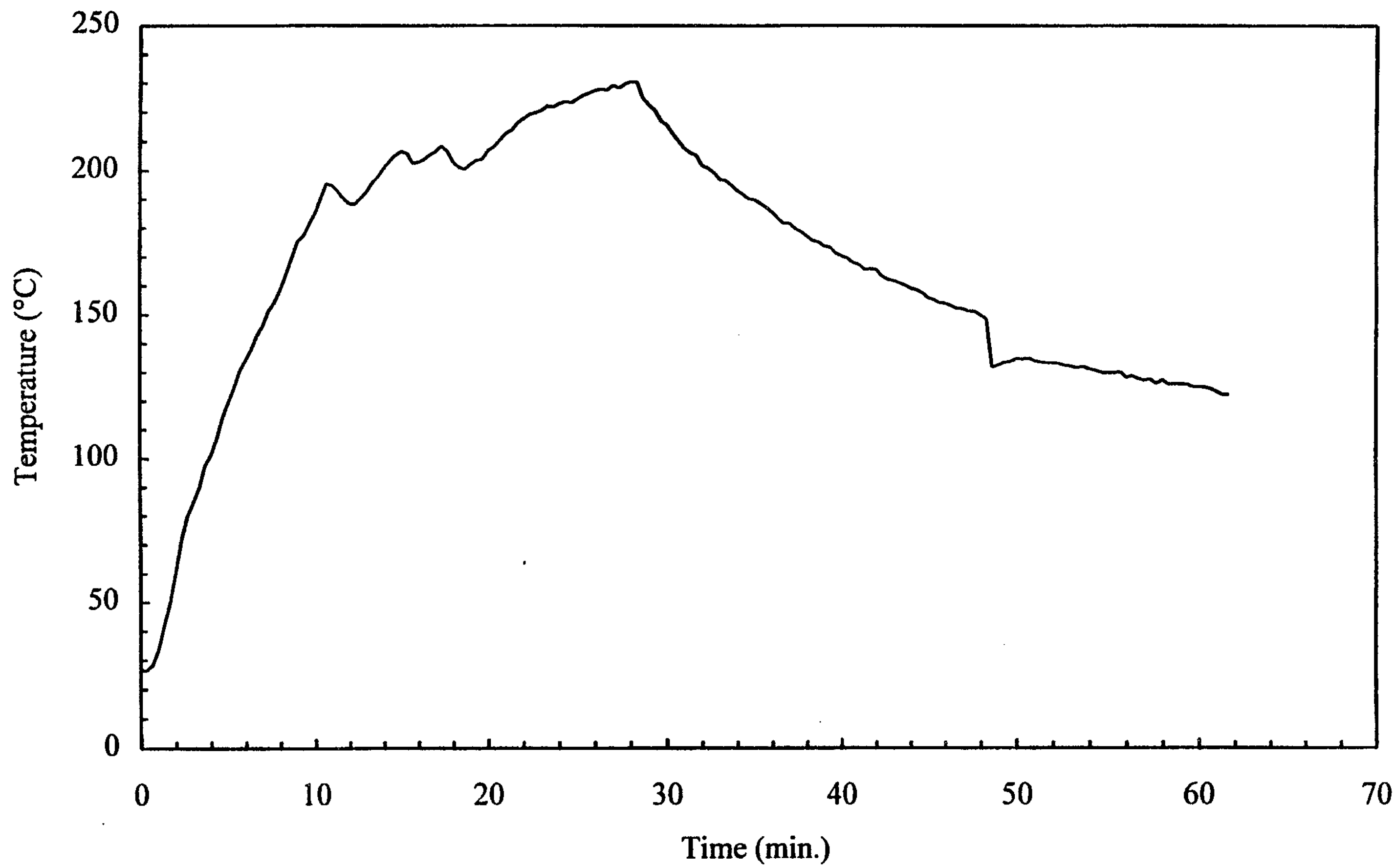

Fig. A39 - Overhead deck temperature measured at 2-17-2

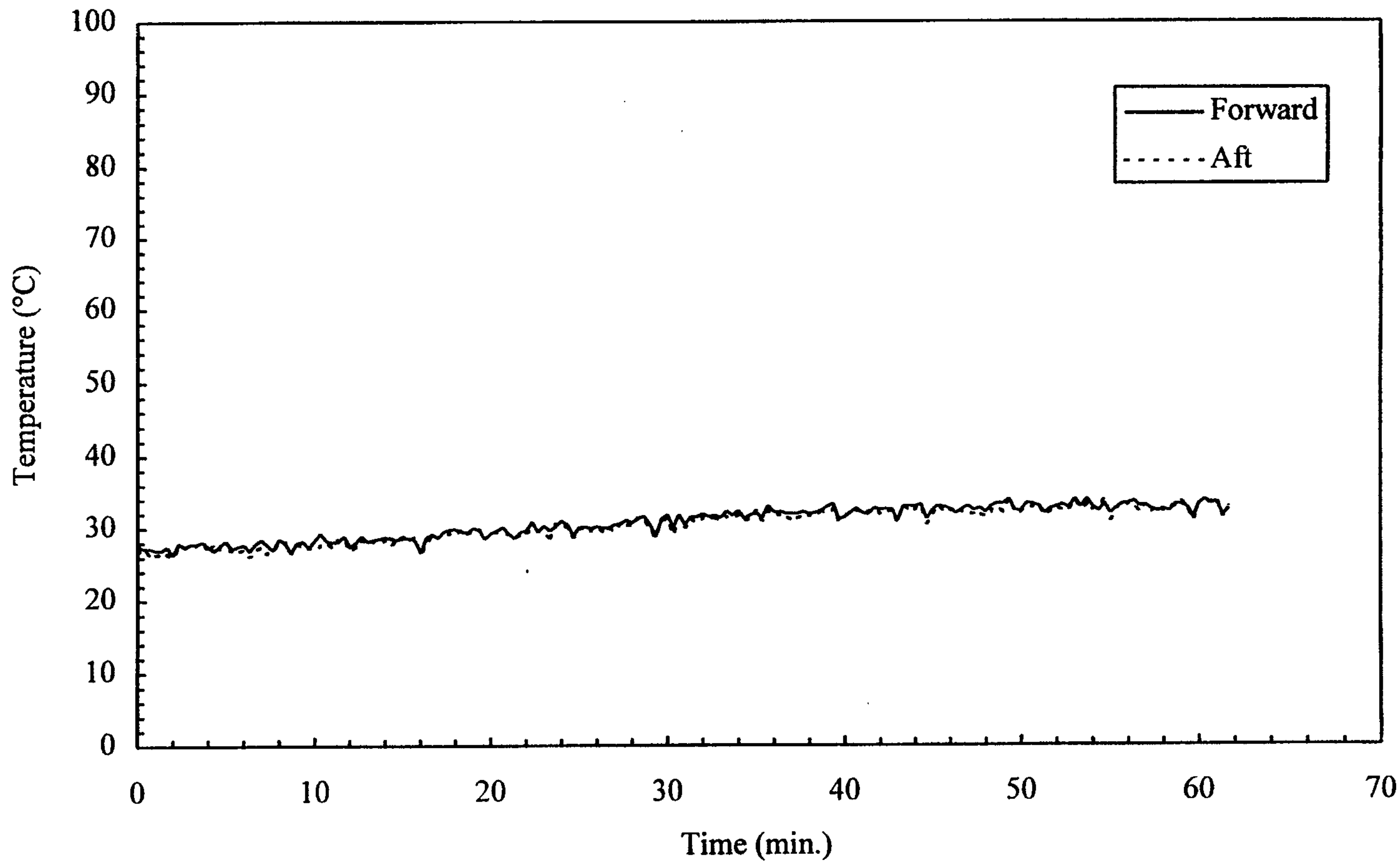

Fig. A40 - Bulkhead temperatures measure 1.5 m (5.0 ft) above the deck at 3-22-0

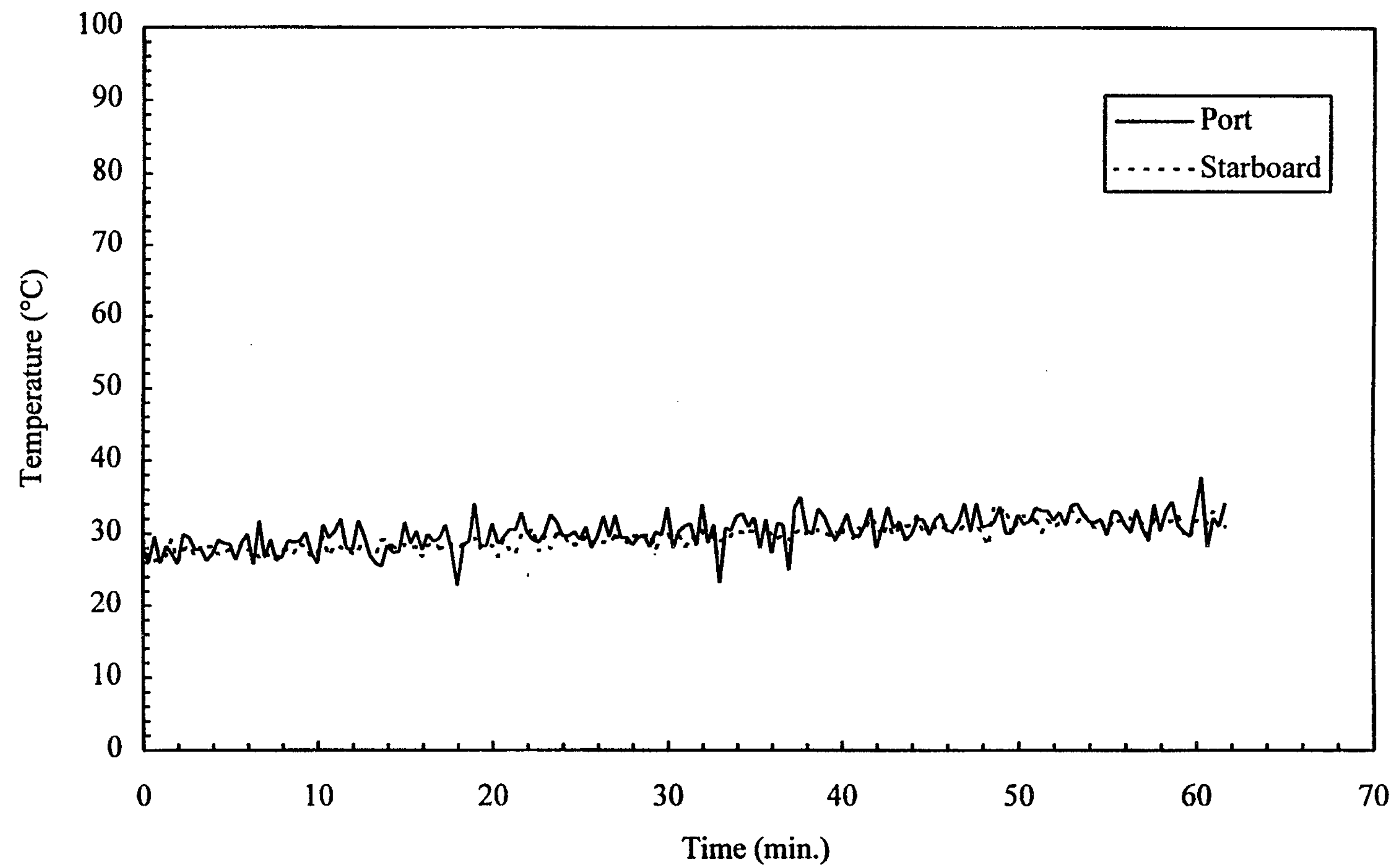

Fig. A41 - Bulkhead temperature measured 1.5 m (5.0 ft) above the deck at 3-17-1

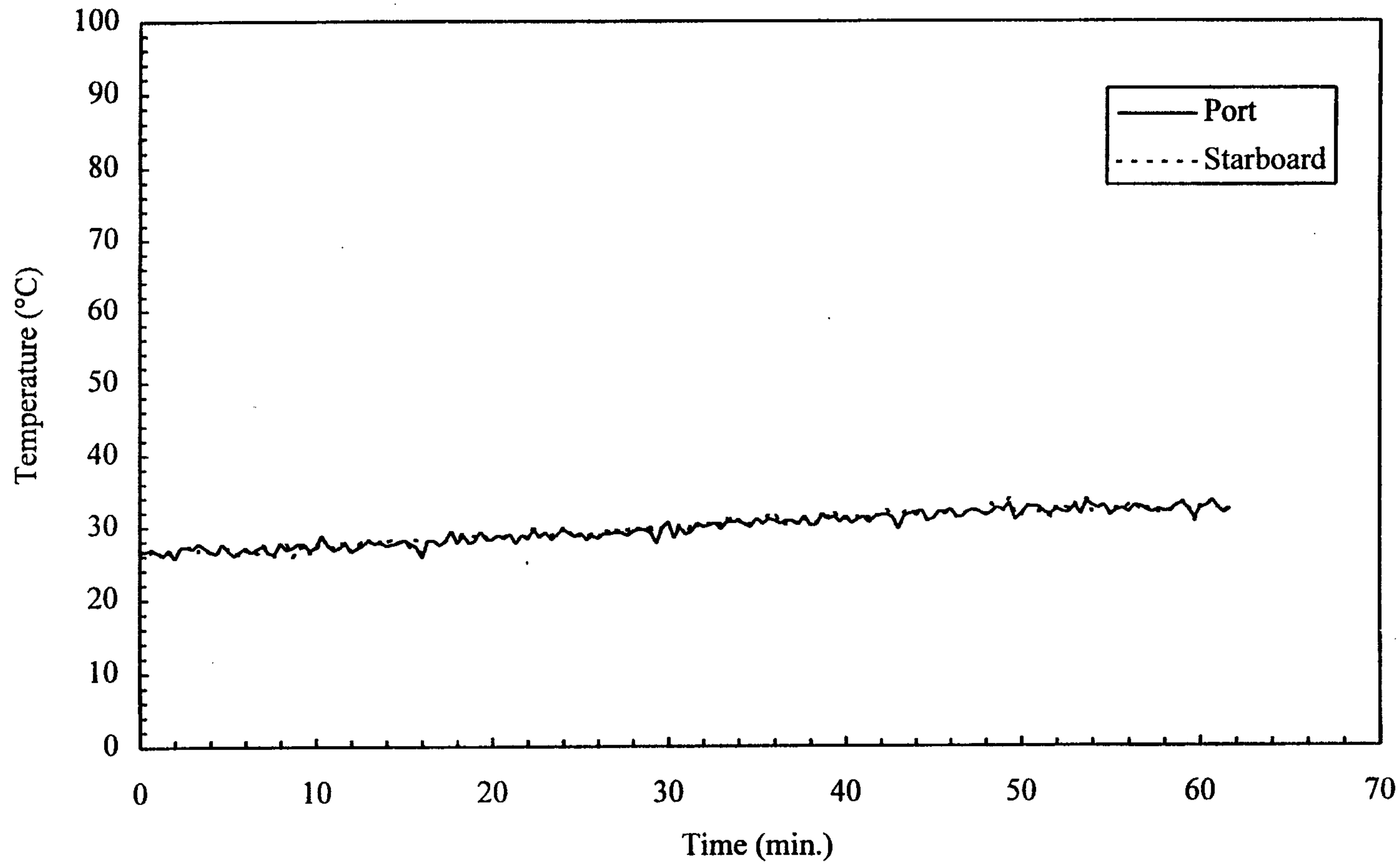

Fig. A42 - Bulkhead temperature measured 1.5 m (5.0 ft) above the deck at 3-17-2

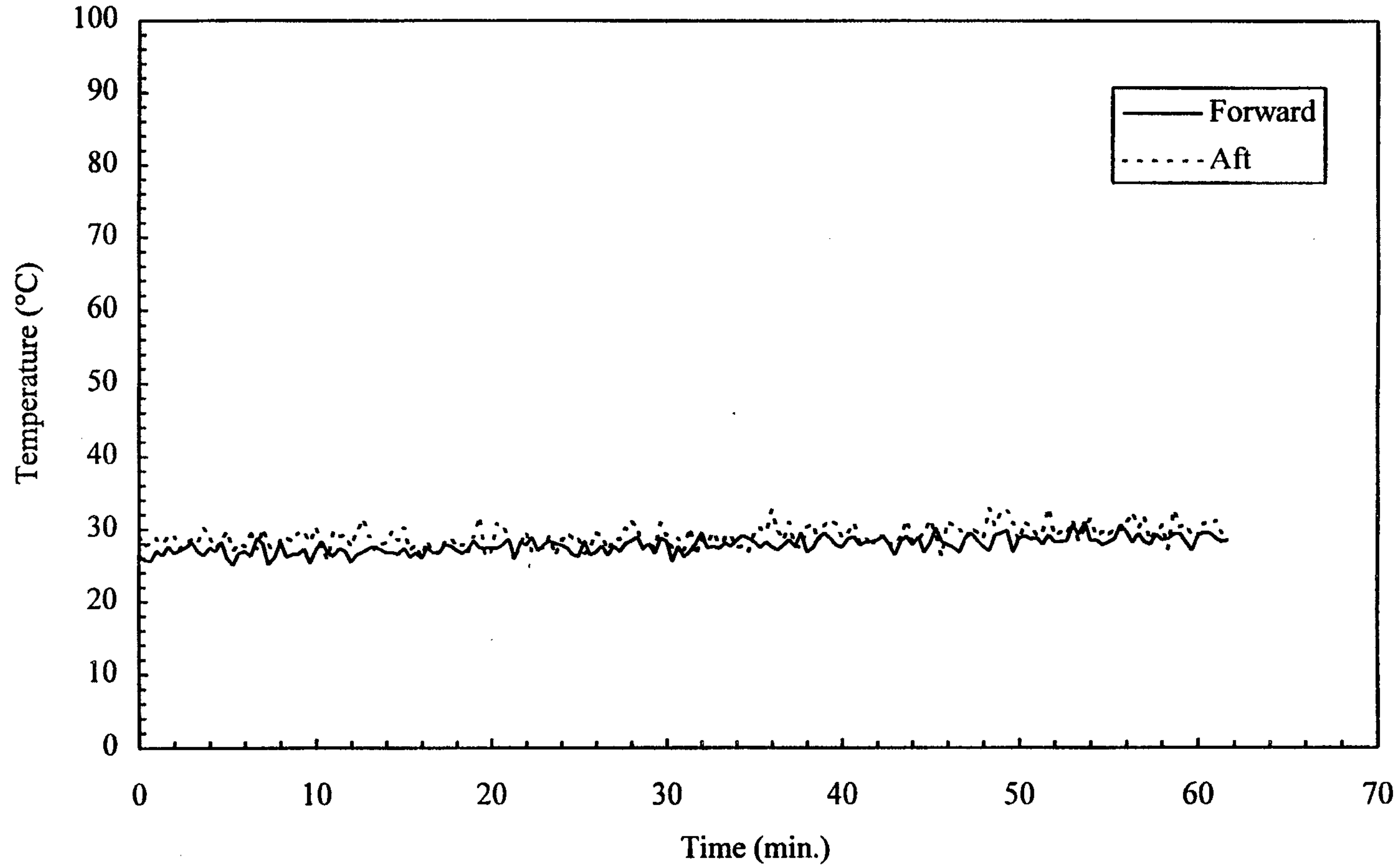

Fig. A43 - Bulkhead temperature measured 1.5 m (5.0 ft) above the deck at 3-15-0

Appendix B

Measure of Performance Data

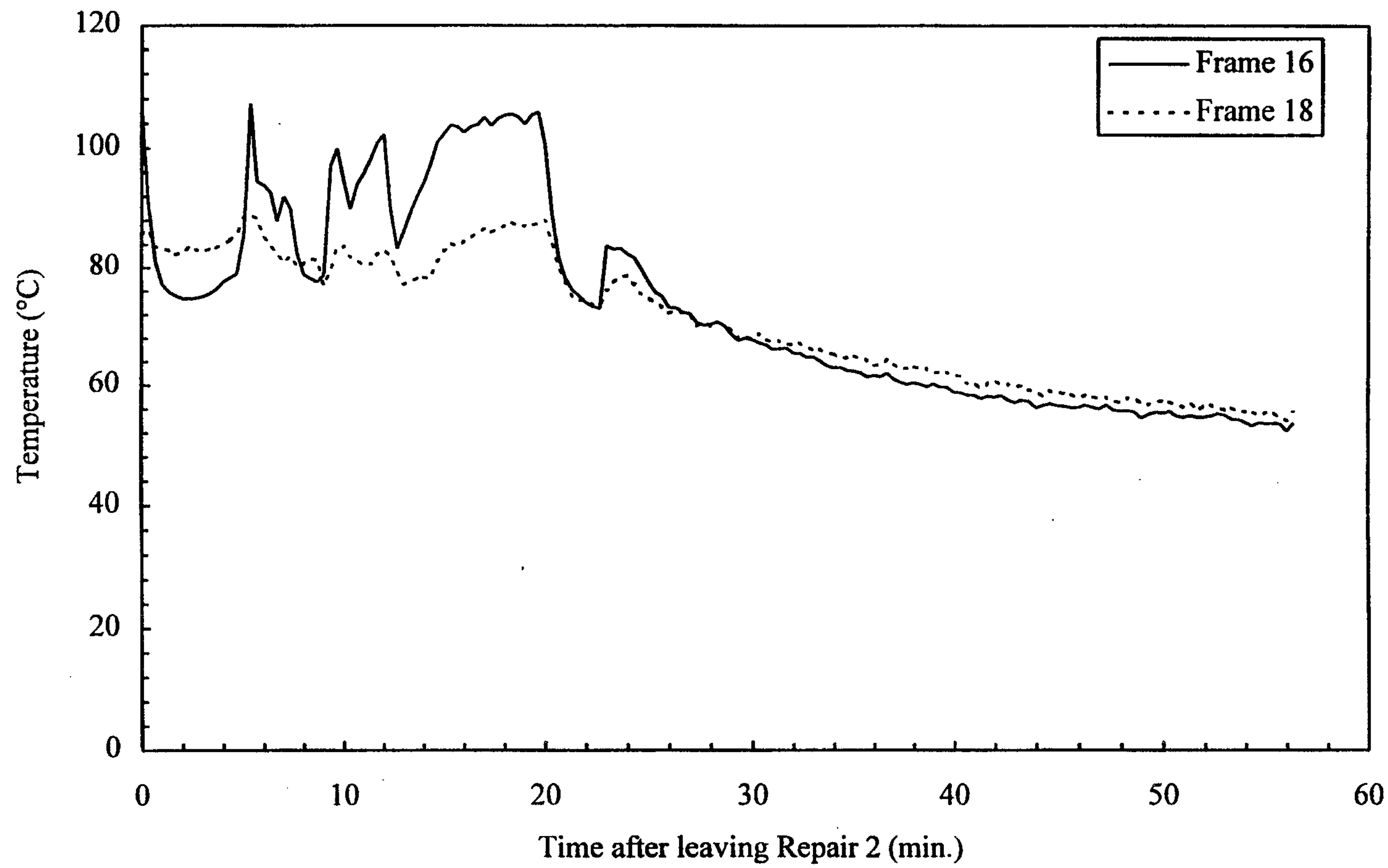

Fig. B1 - Average overhead temperatures in GSK by frame number, Test scba_03

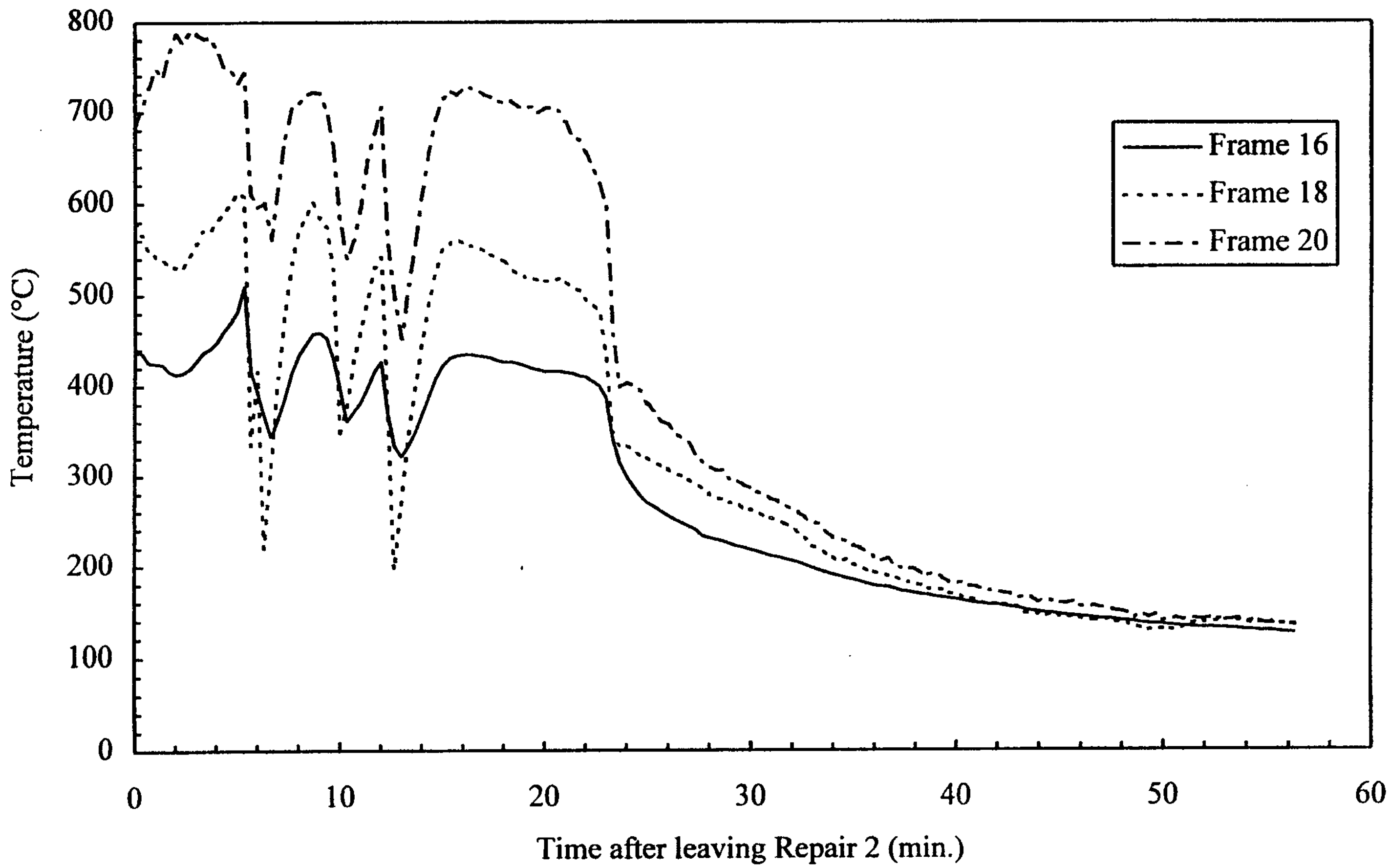

Fig. B2 - Average overhead temperatures in Storage by frame number, Test scba_03

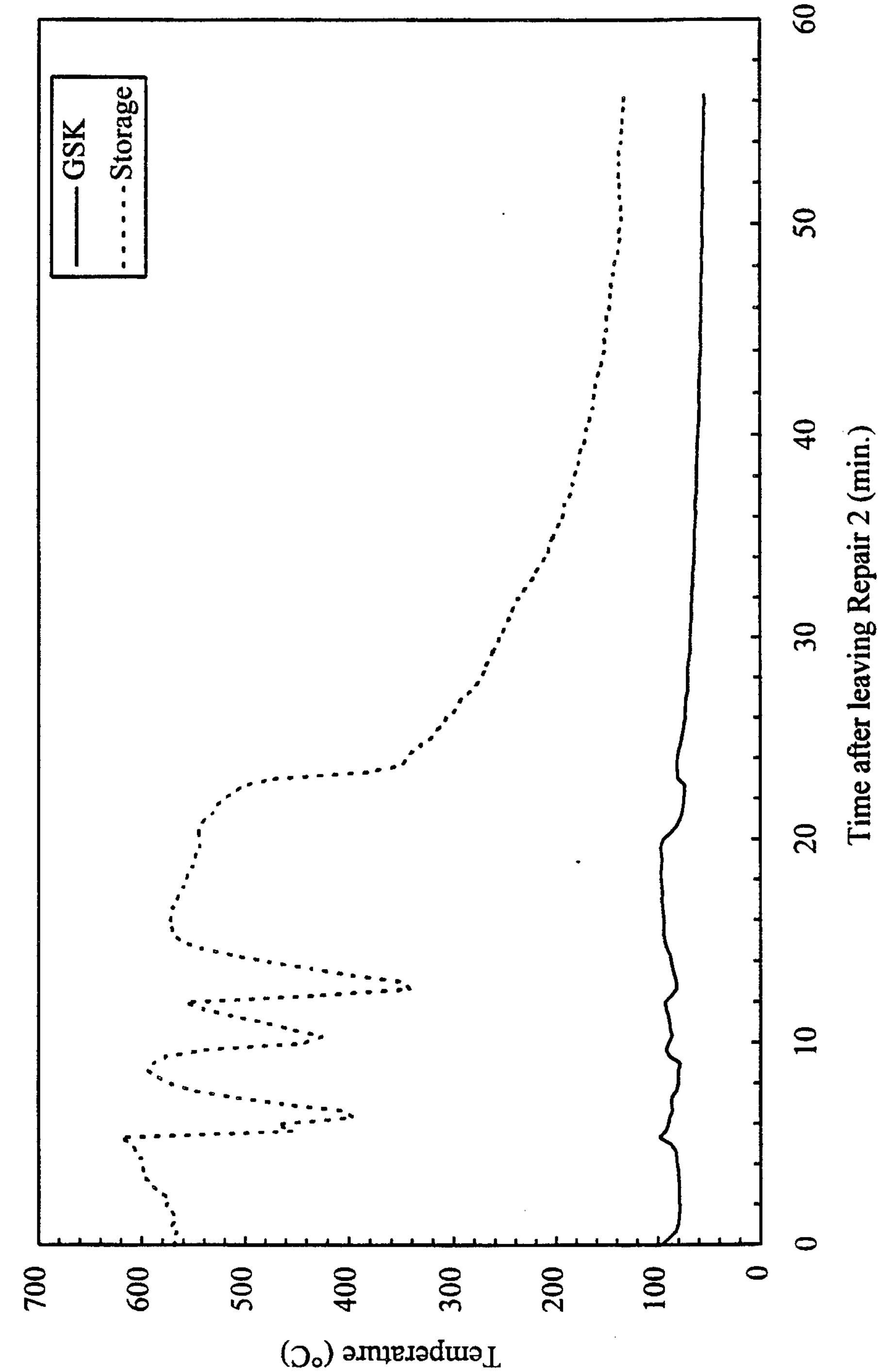

Fig. B3 - Average overhead temperatures in GSK and Storage, Test scba_03

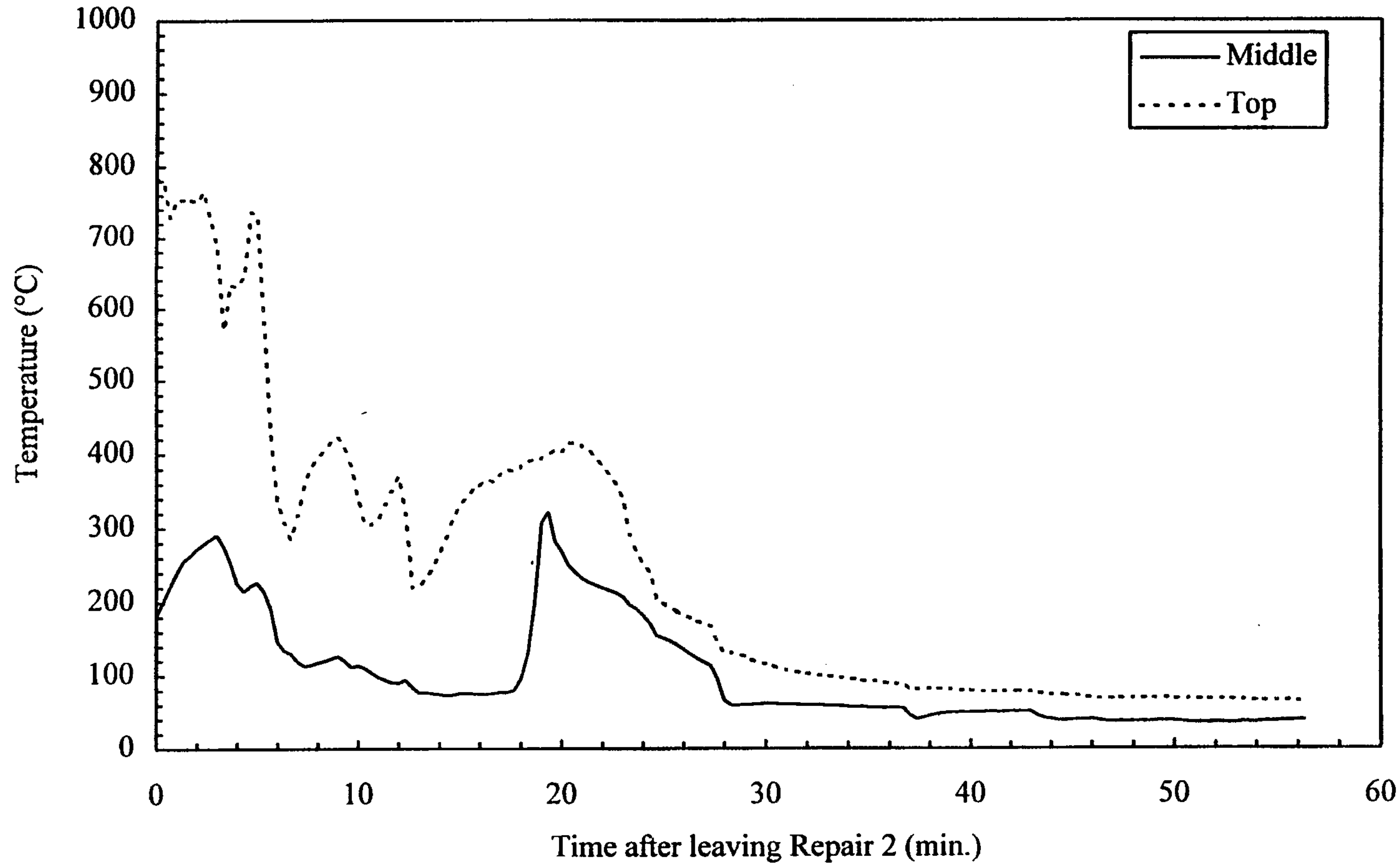

Fig. B4 - Crib 1 temperatures, Test scba_03

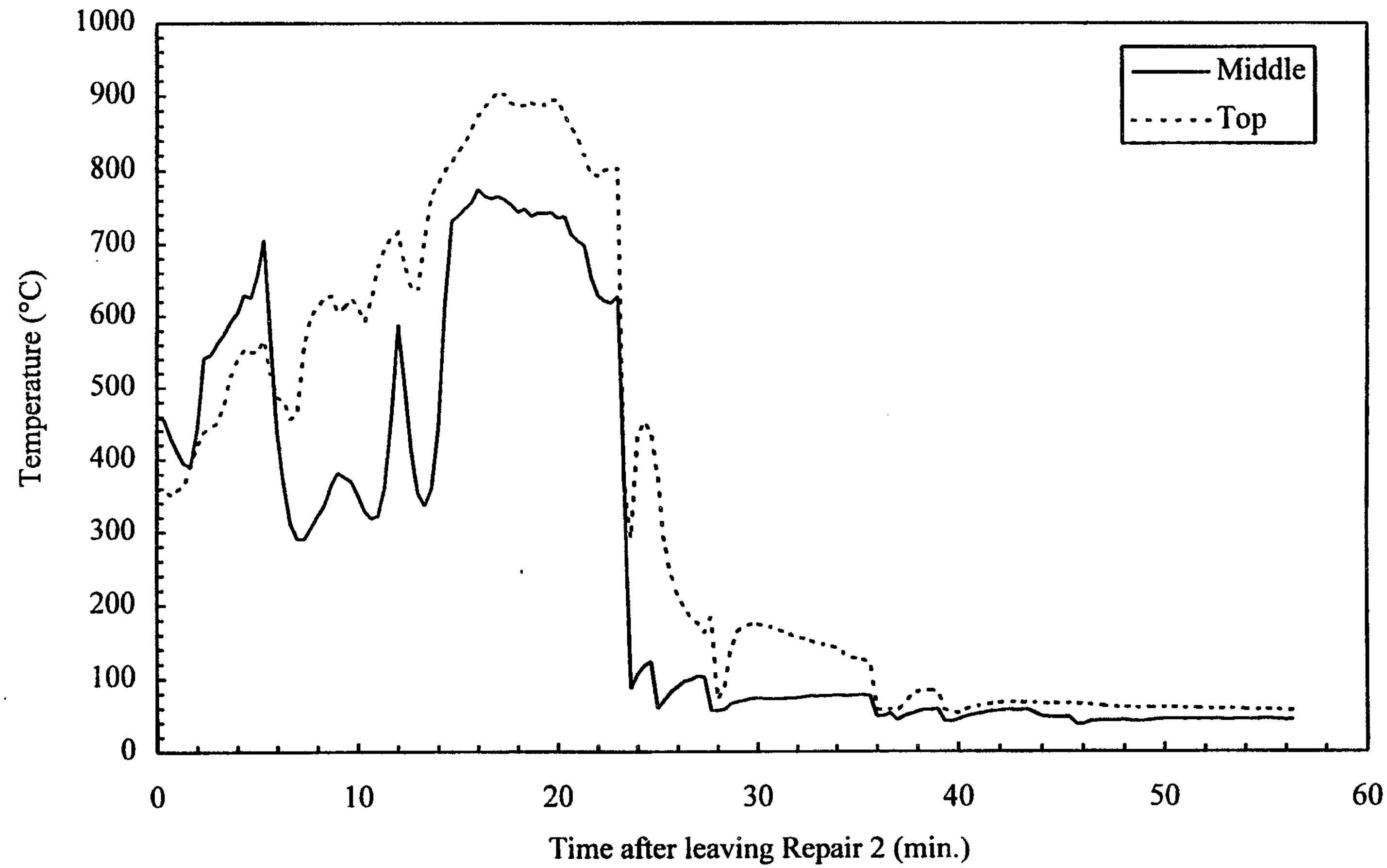

Fig. B5 - Crib 2 temperatures, Test scba_03

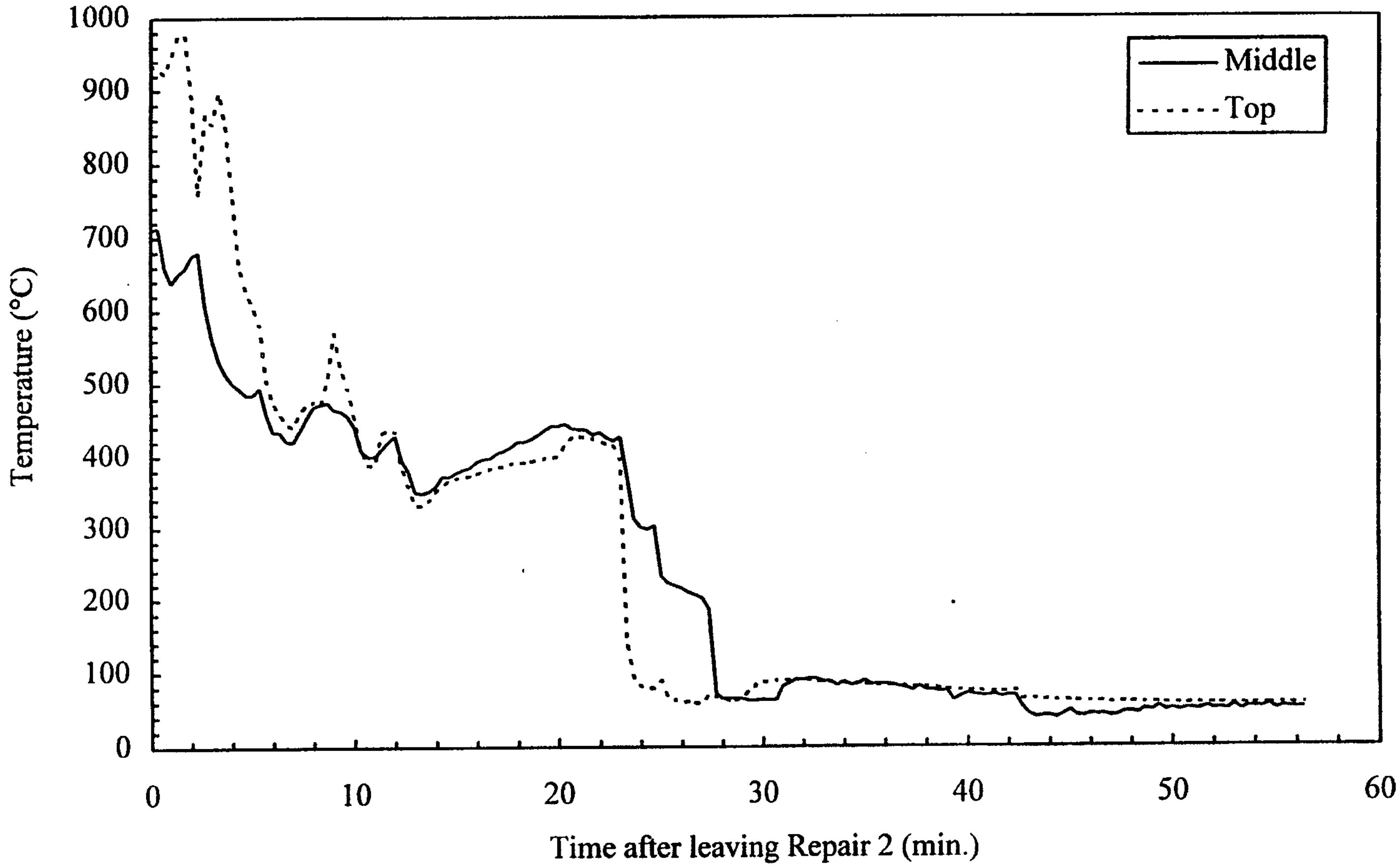

Fig. B6 - Crib 3 temperatures, Test scba_03

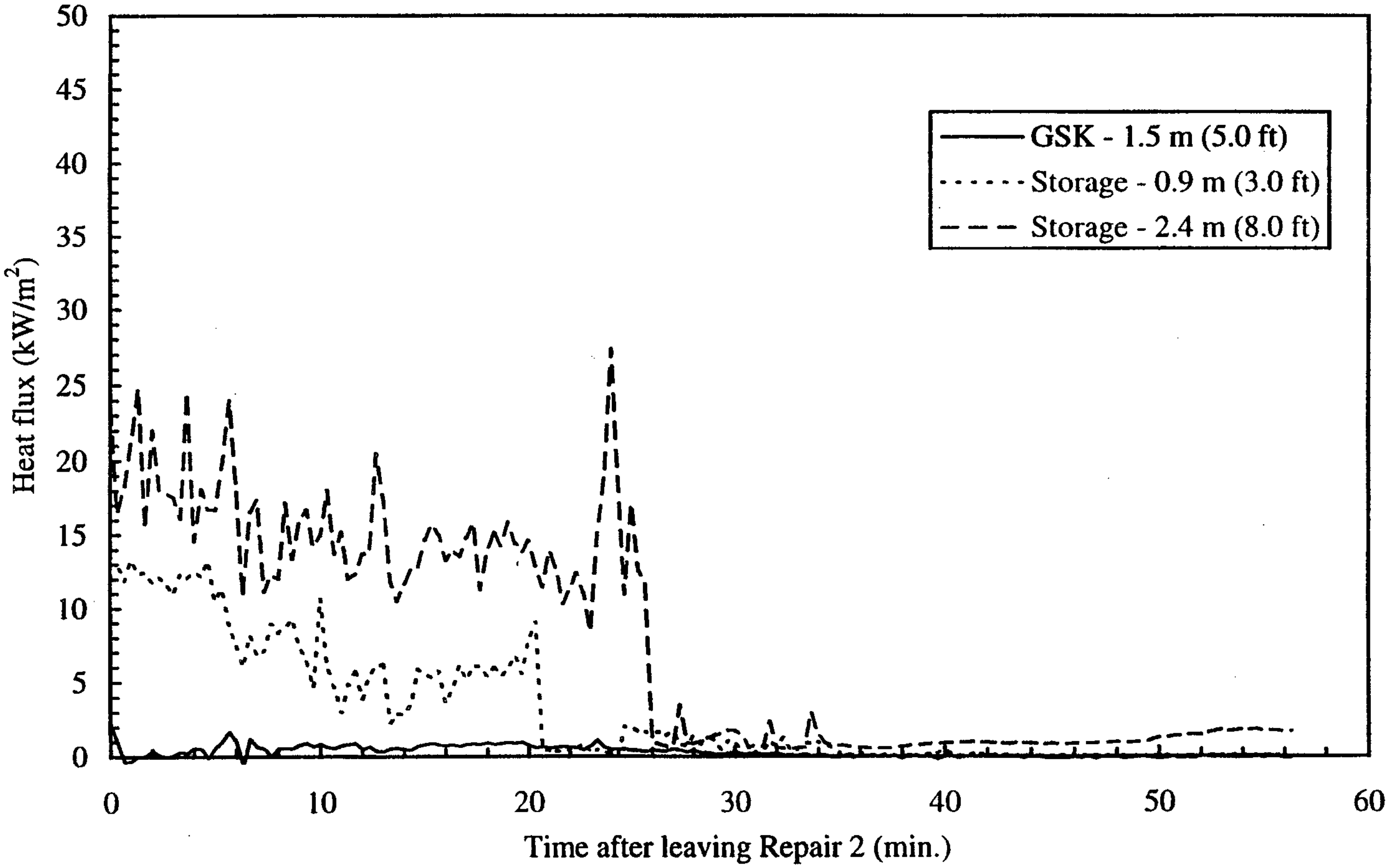

Fig. B7 - Total heat flux in GSK and Storage, Test scba_03

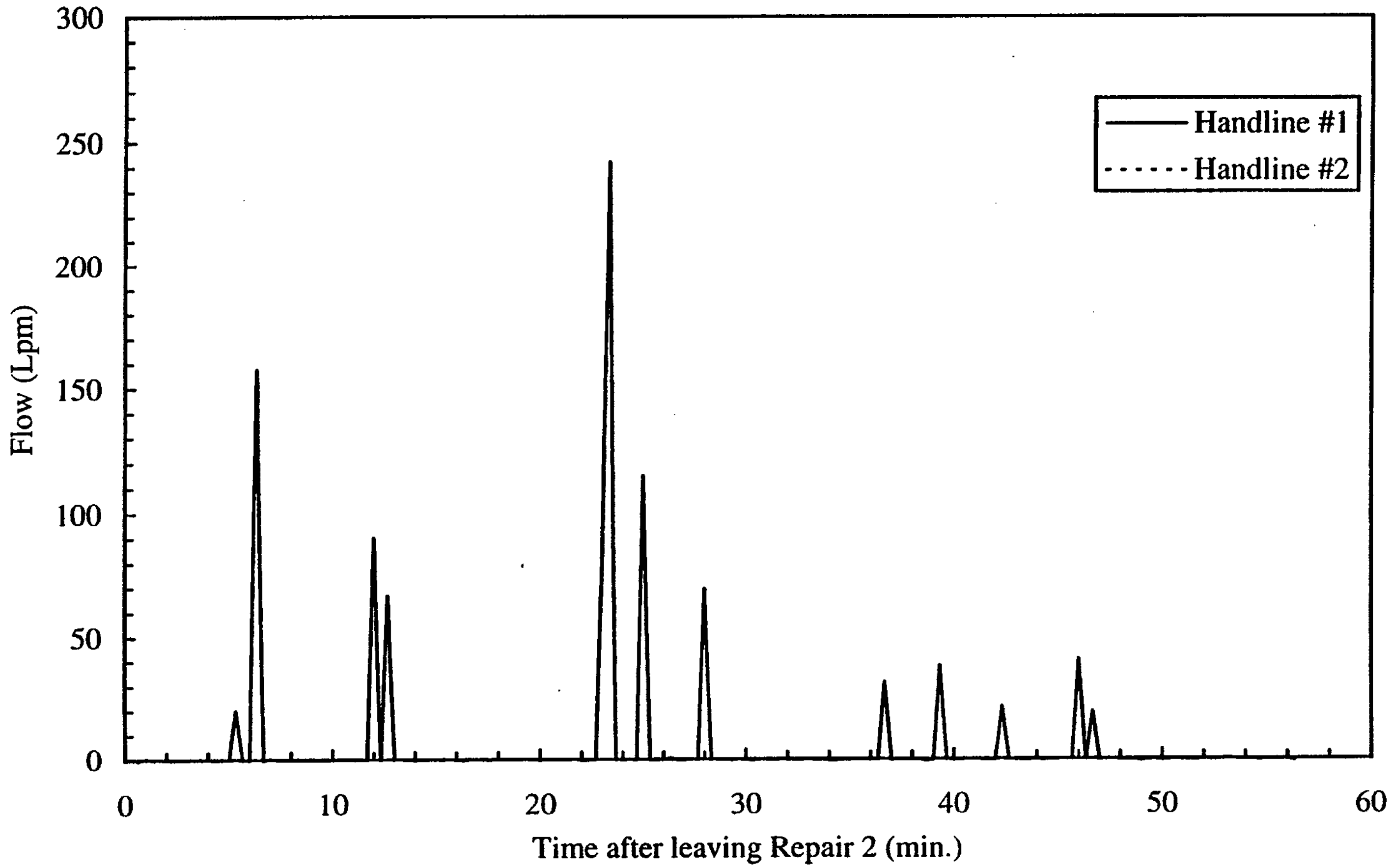

Fig. B8 - Second deck handline flows, Test scba_03

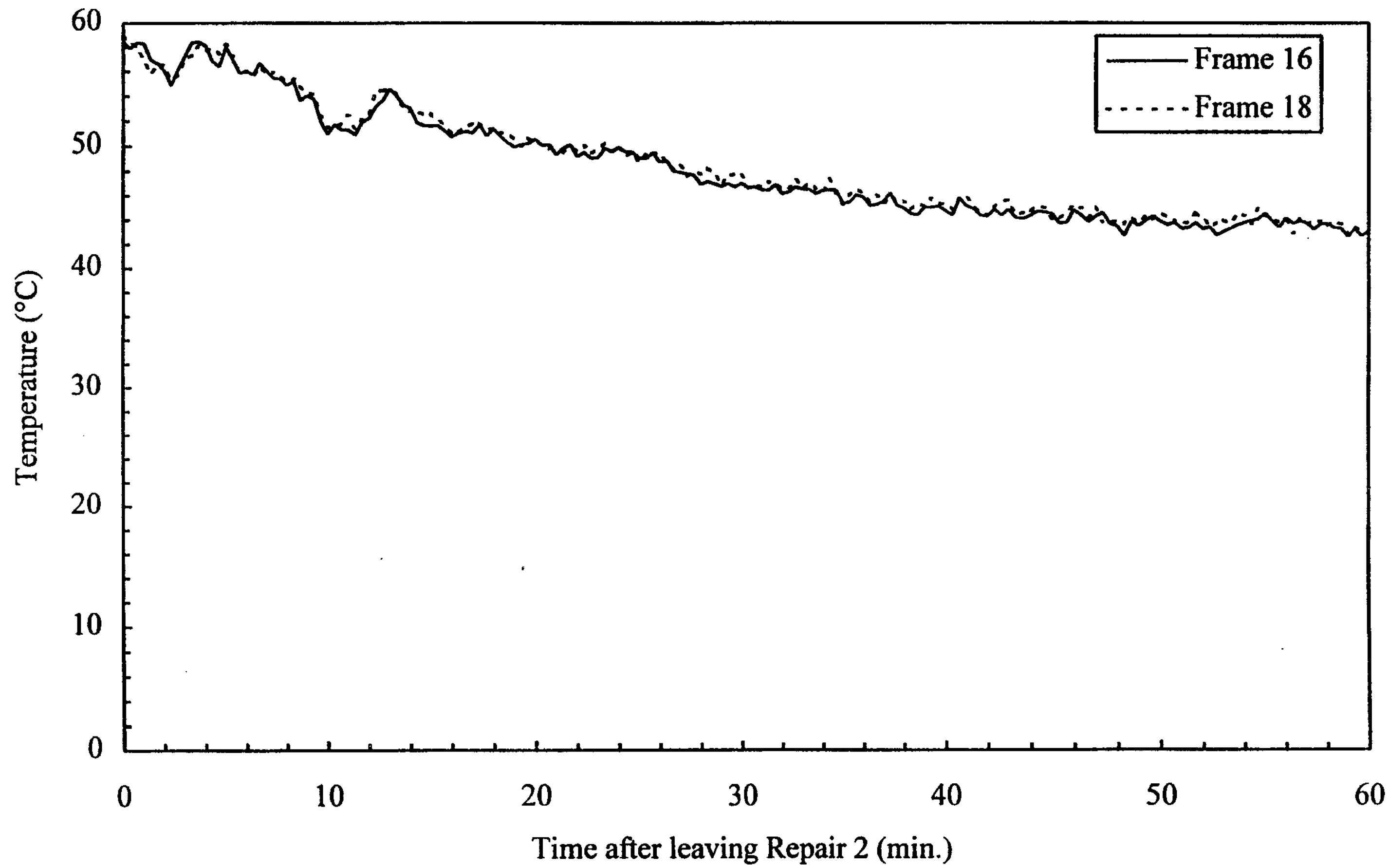

Fig. B9 - Average overhead temperatures in GSK by frame number, Test scba_04

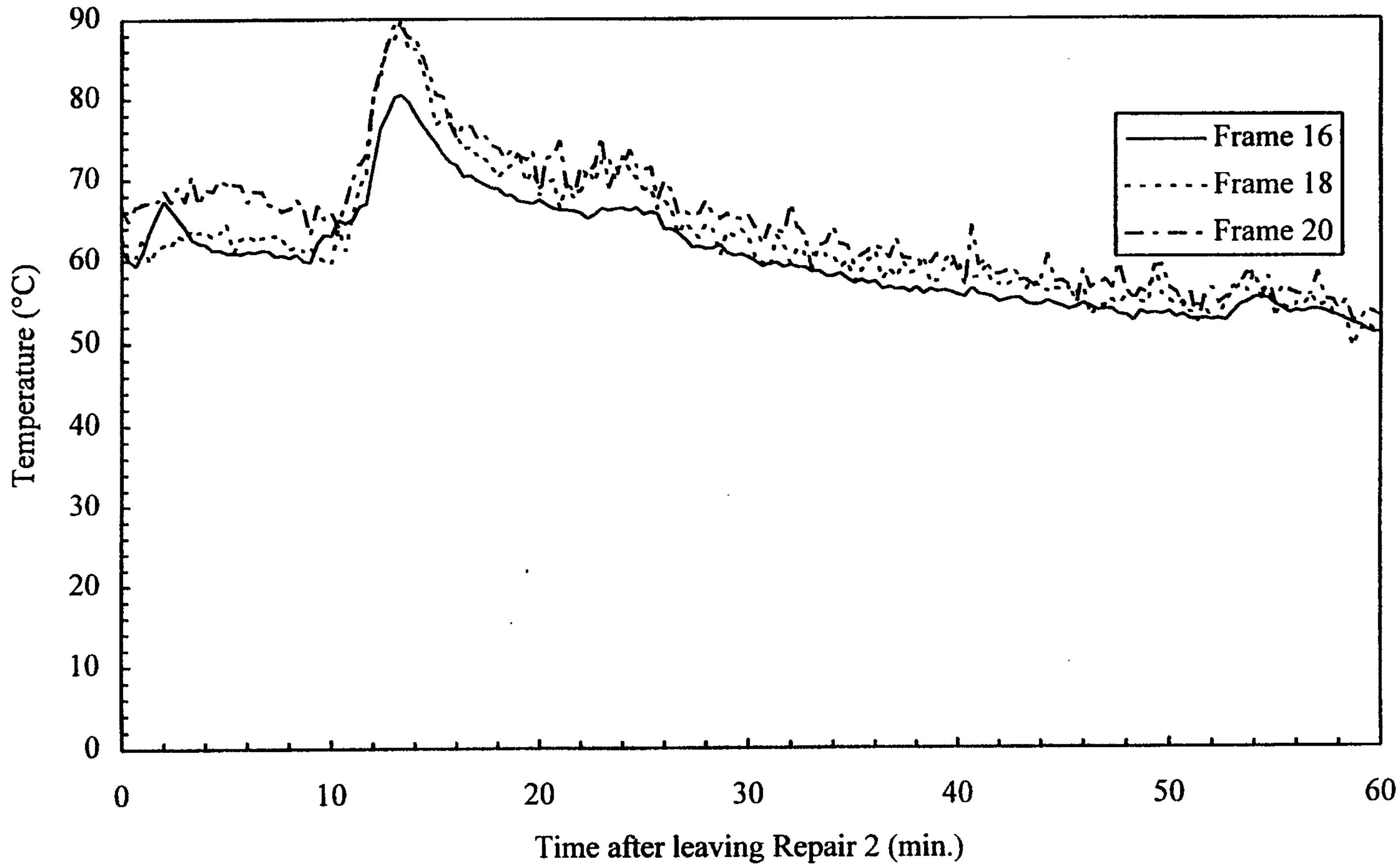

Fig. B10 - Average overhead temperatures in Storage by frame number, Test scba_04

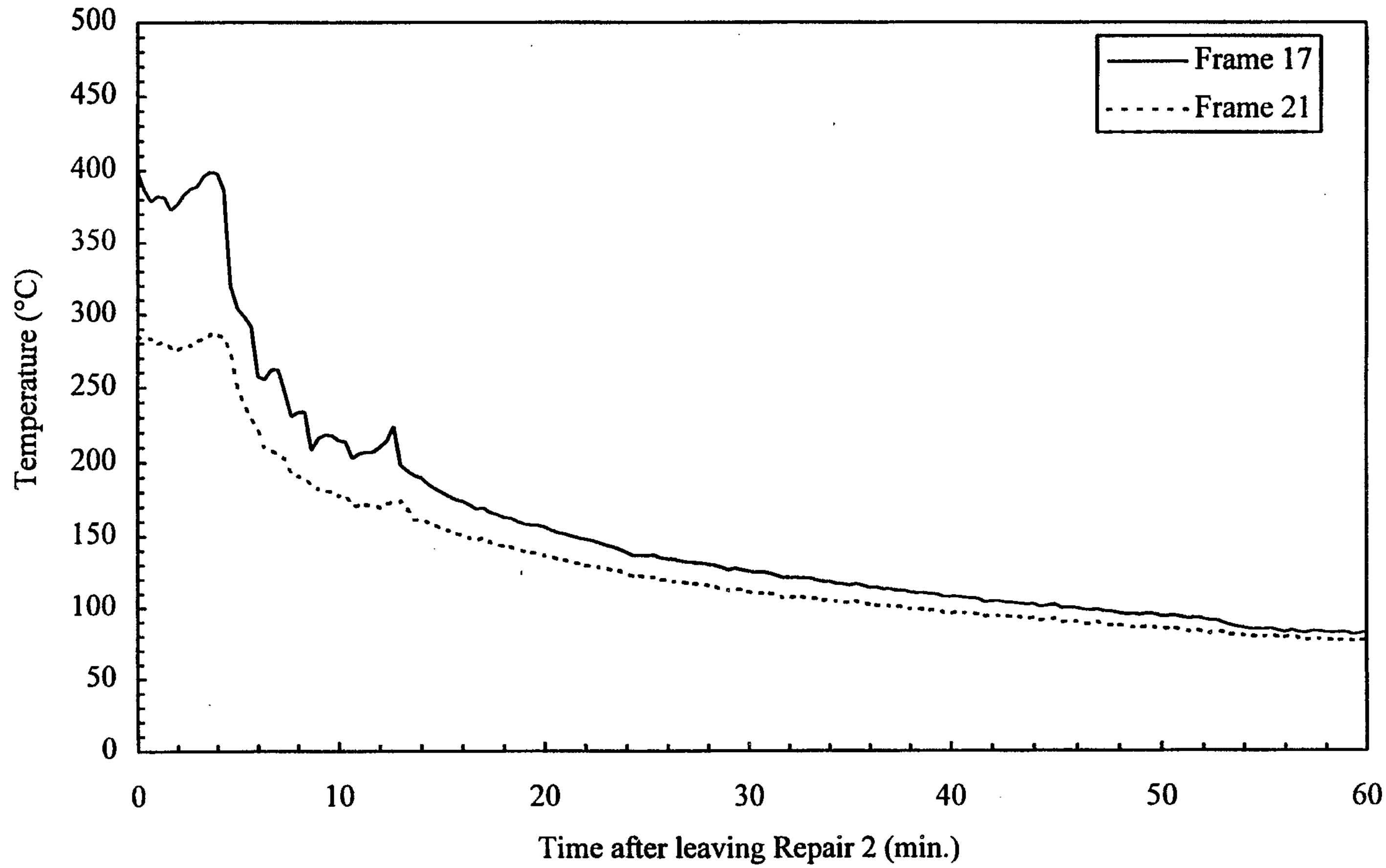

Fig. B11 - Average overhead temperatures in Berthing 2 by frame number, Test scba_04

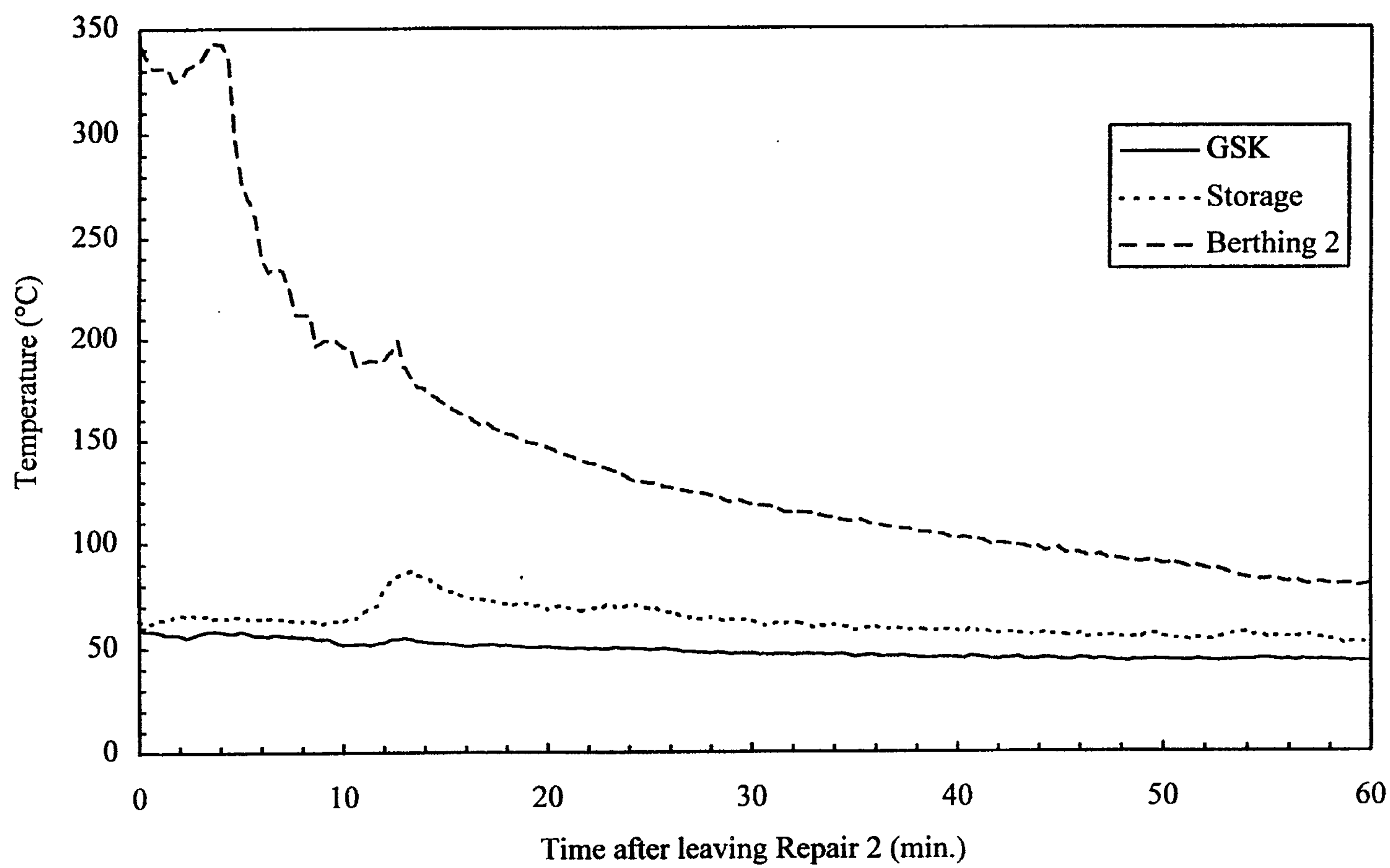

Fig. B12 - Average overhead temperatures in test compartments, Test scba_04

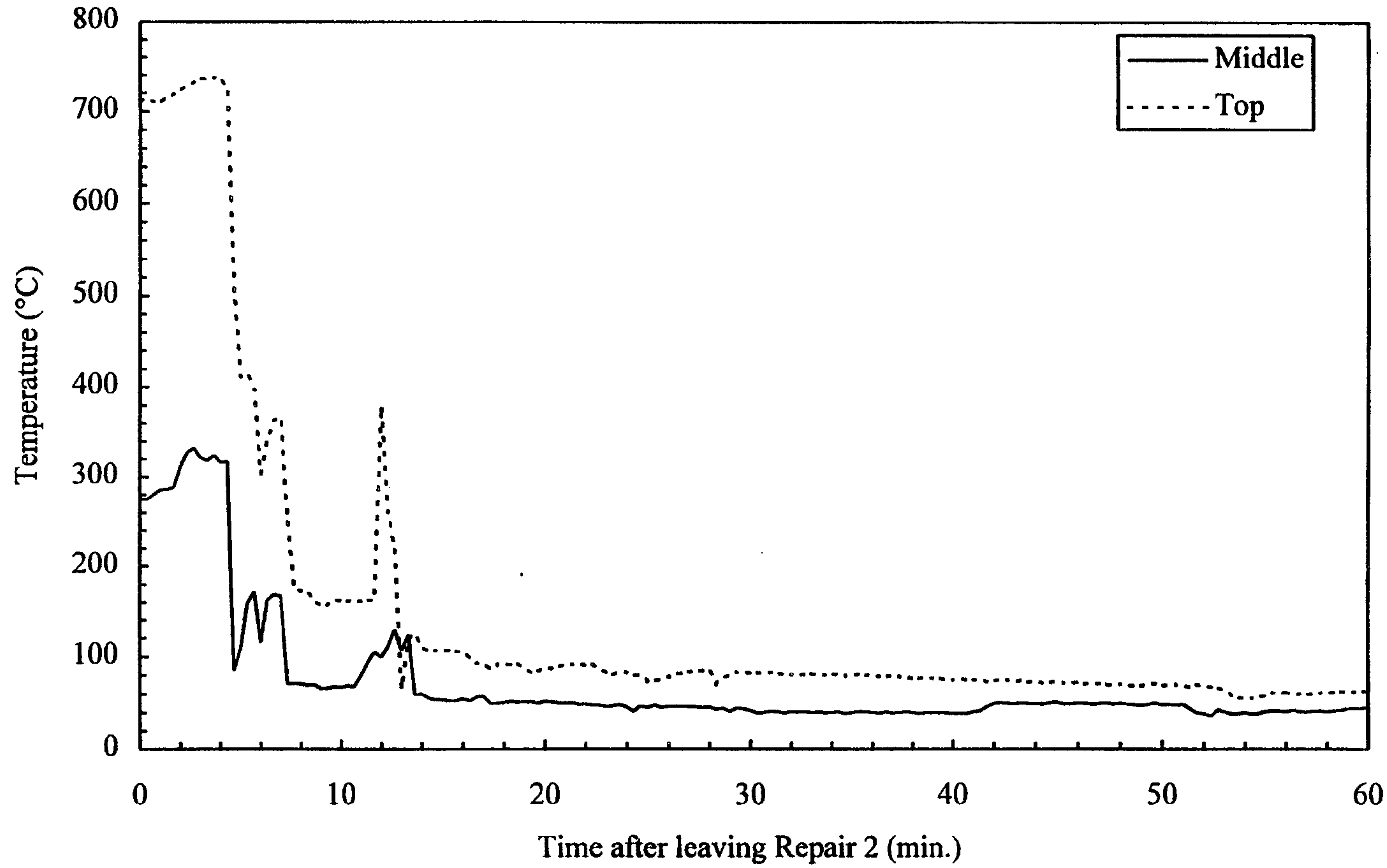

Fig. B13 - Crib 4 temperatures, Test scba_04

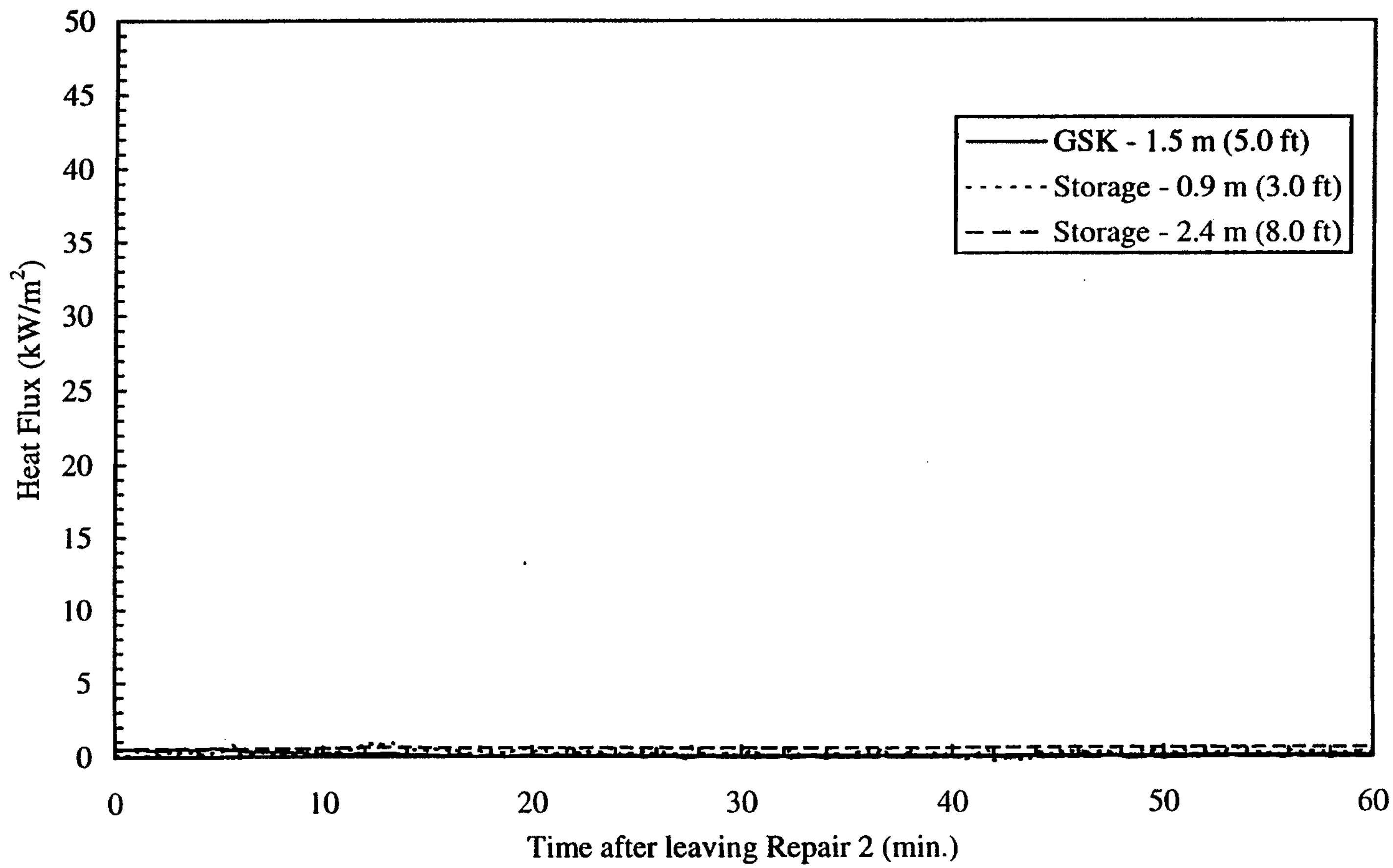

Fig. B14 - Total heat flux in GSK and Storage, Test scba_04

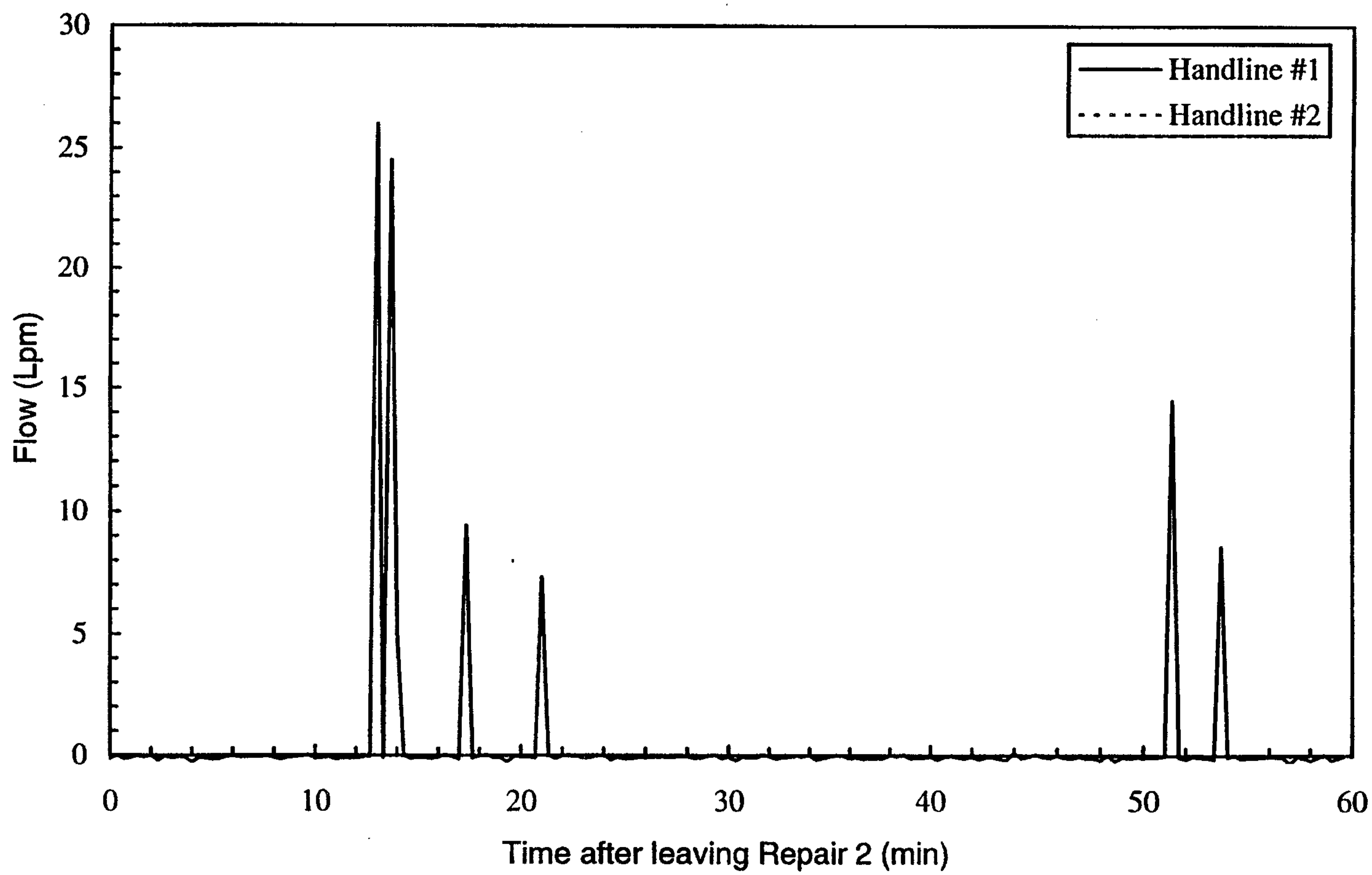

Fig. B15 - Second deck handline flows, Test scba_04

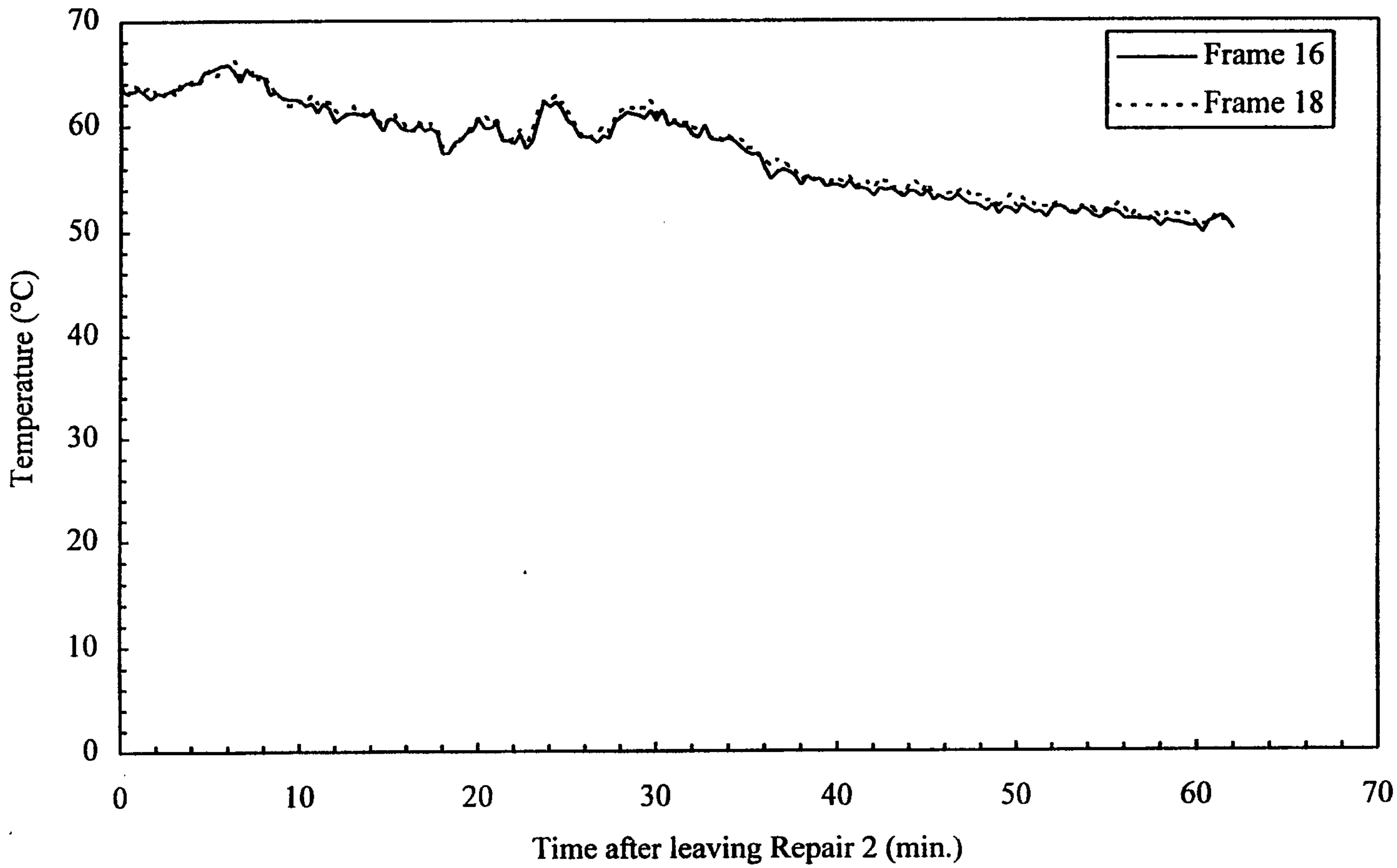

Fig. B16 - Average overhead temperatures in GSK by frame number, Test scba_05

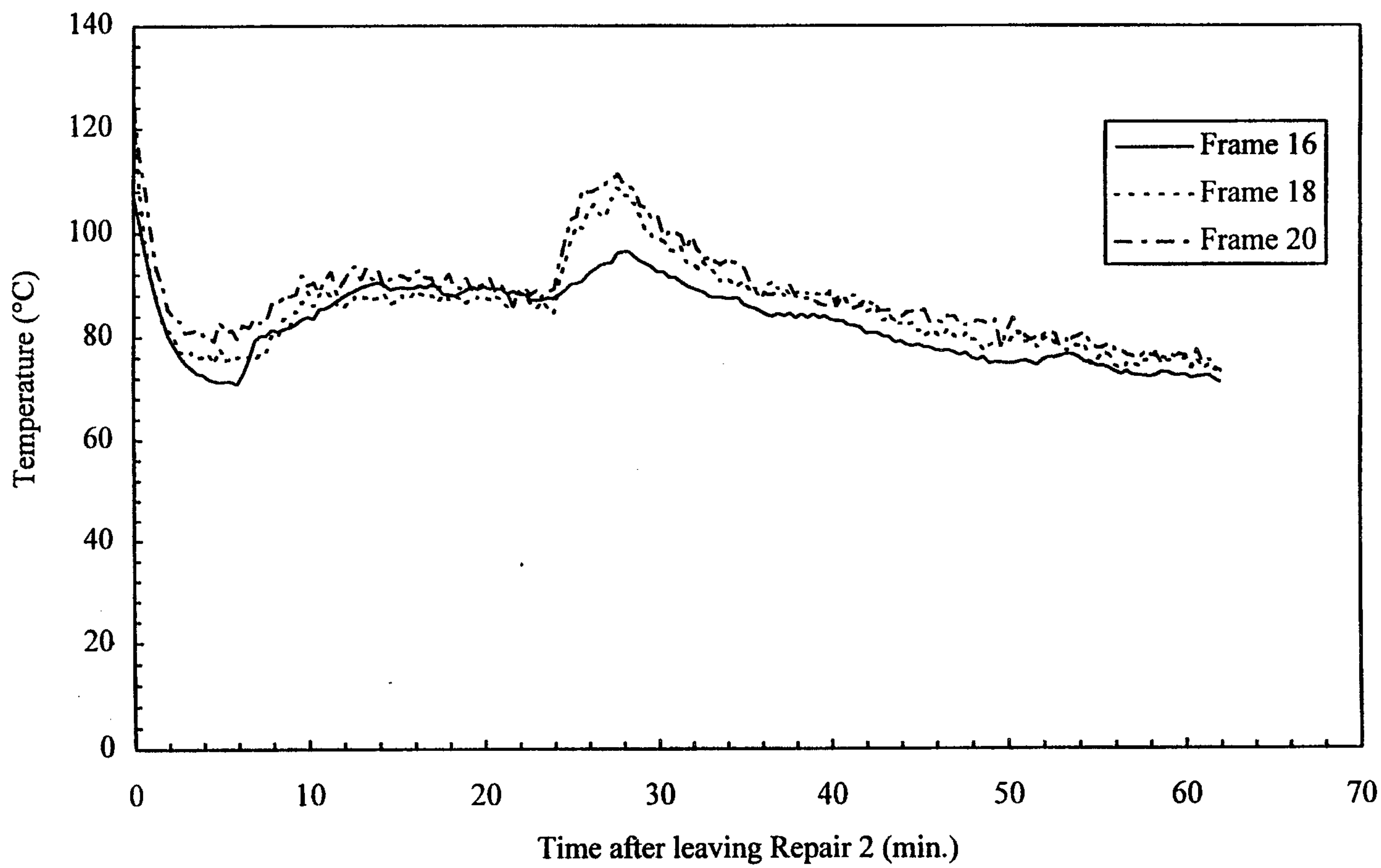

Fig. B17 - Average overhead temperatures in Storage by frame number, Test scba_05

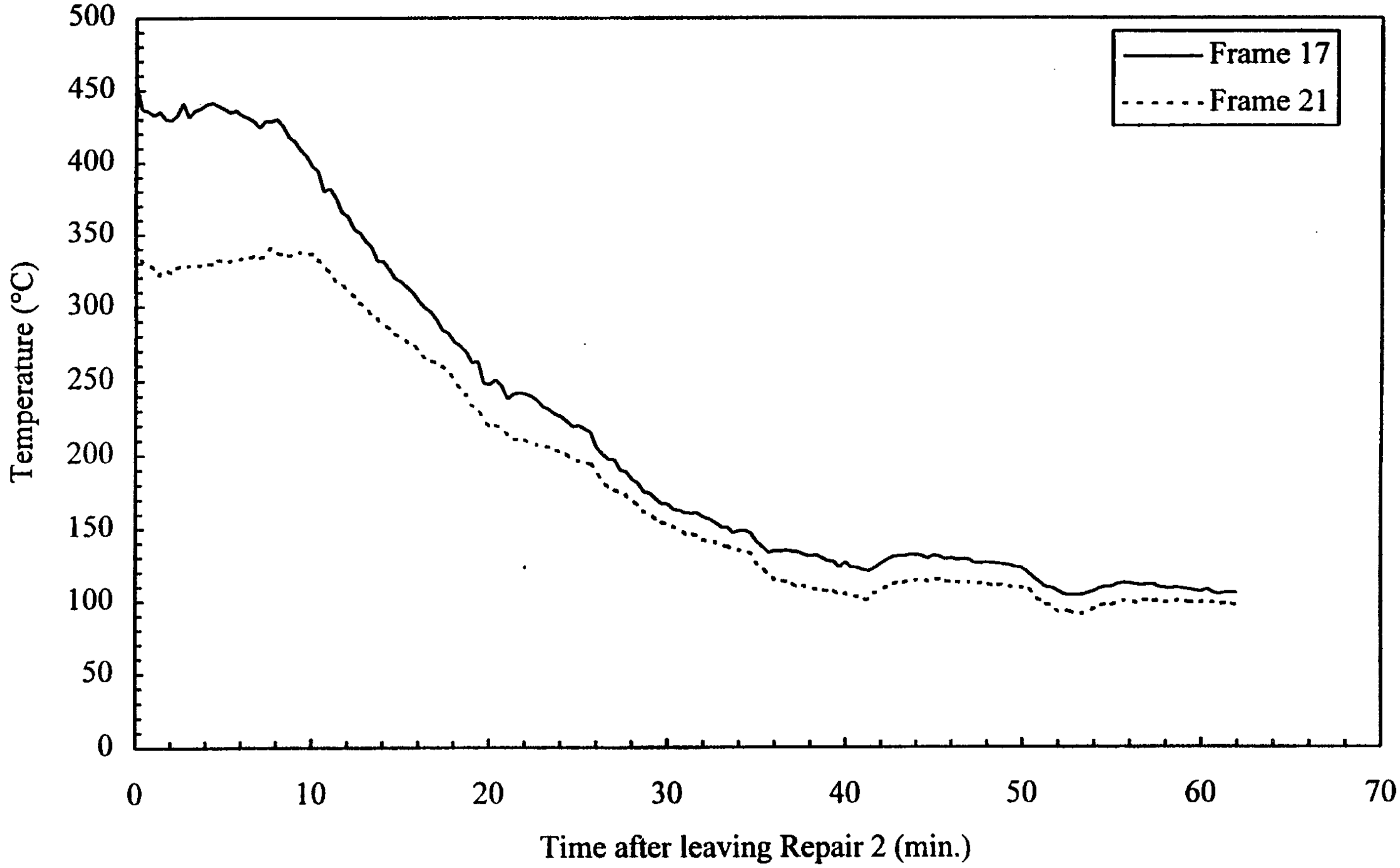

Fig. B18 - Average overhead temperatures in Berthing 2 by frame number, Test scba_05

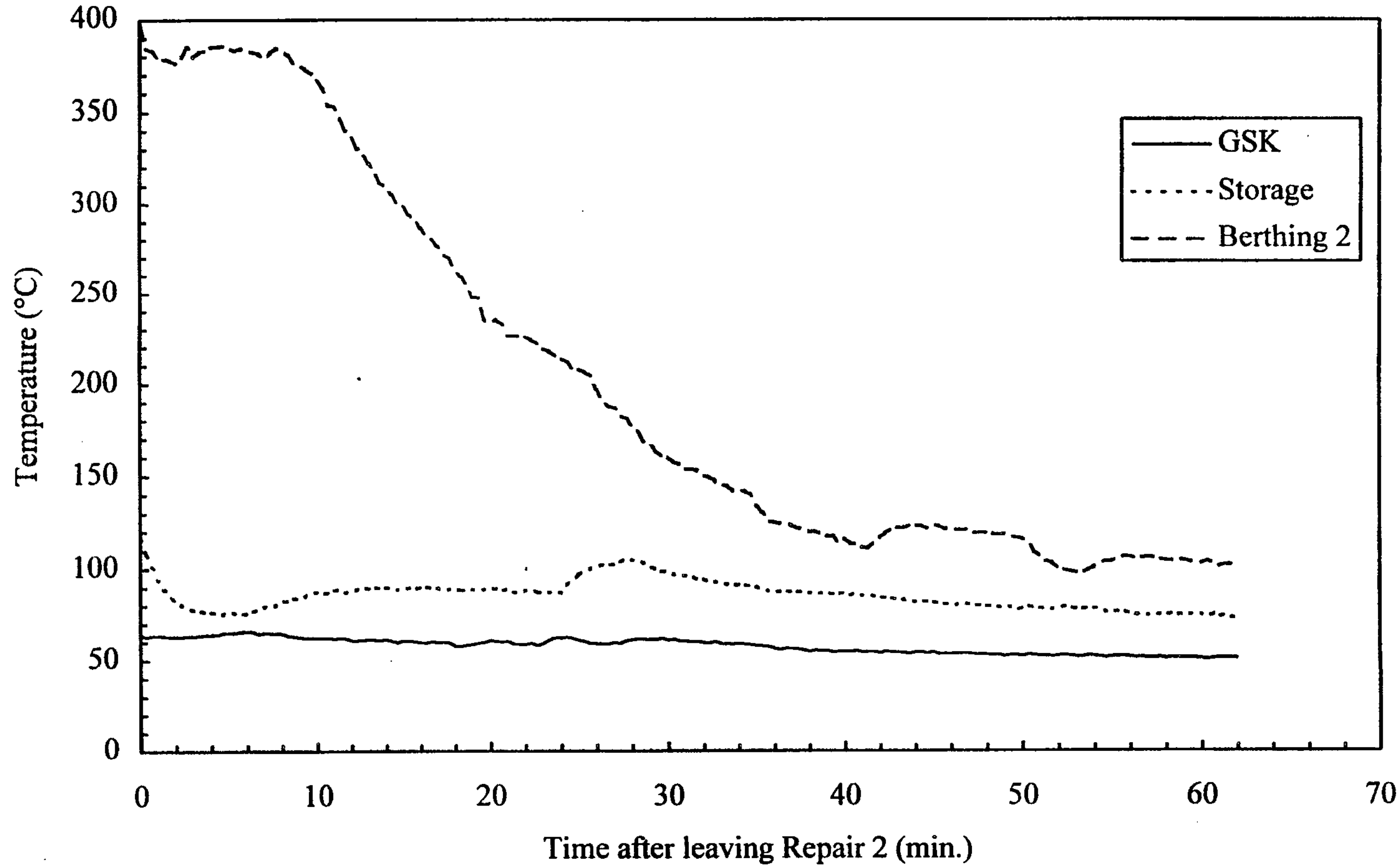

Fig. B19 - Average overhead temperatures in test compartments, Test scba_05

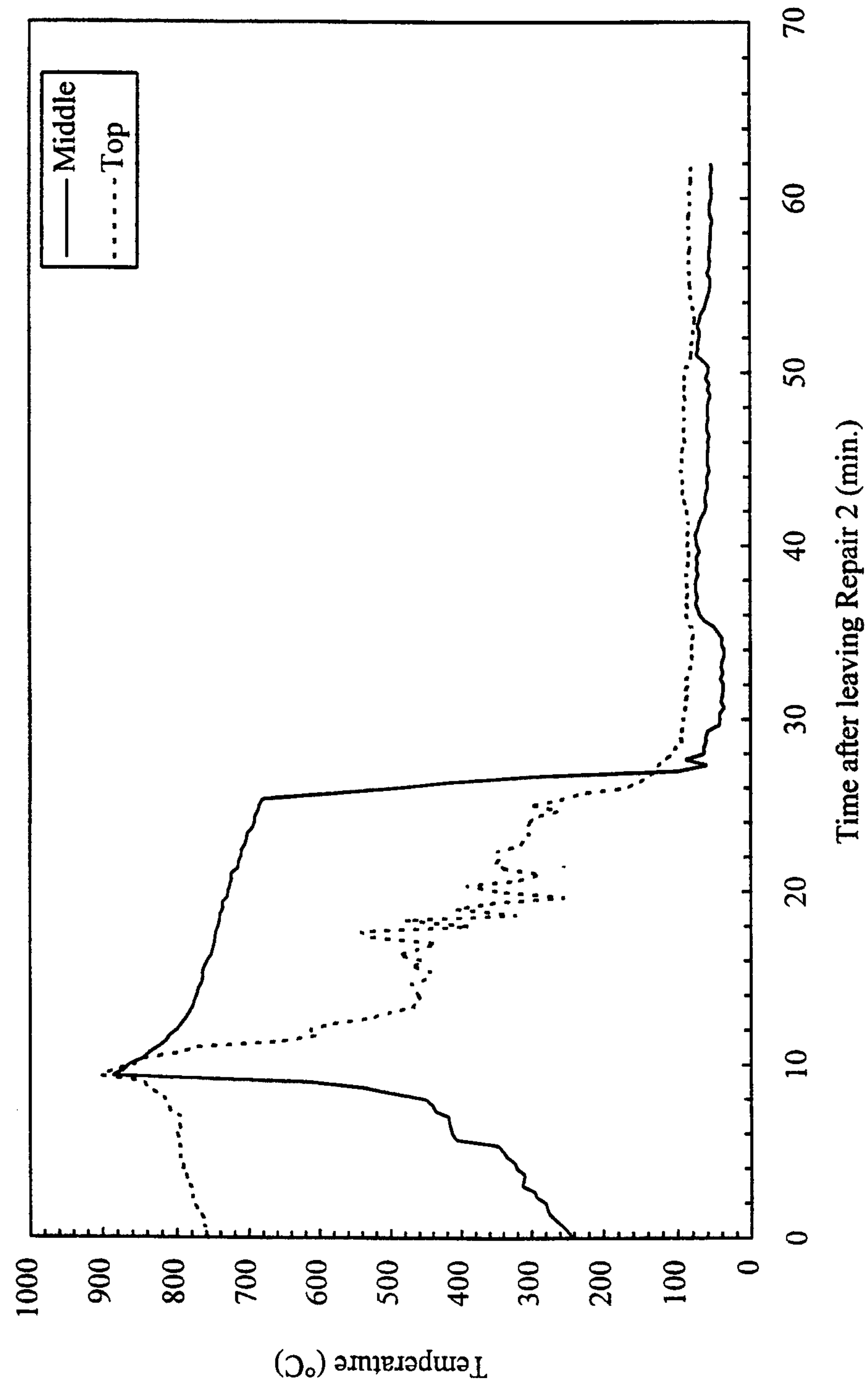

Fig. B20 - Crib 4 temperatures, Test scba_05

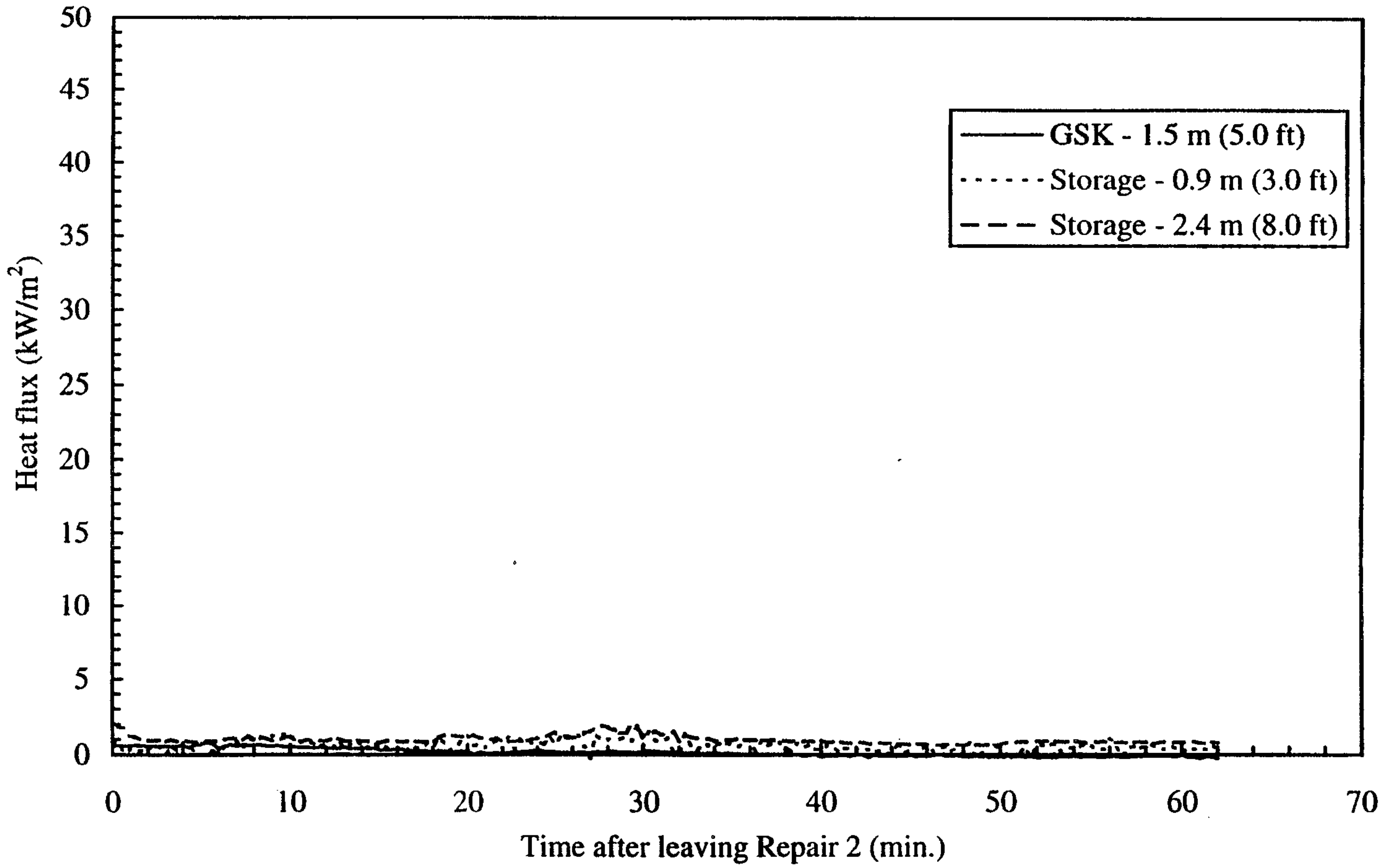

Fig. B21 - Total heat flux in GSK and Storage, Test scba_05

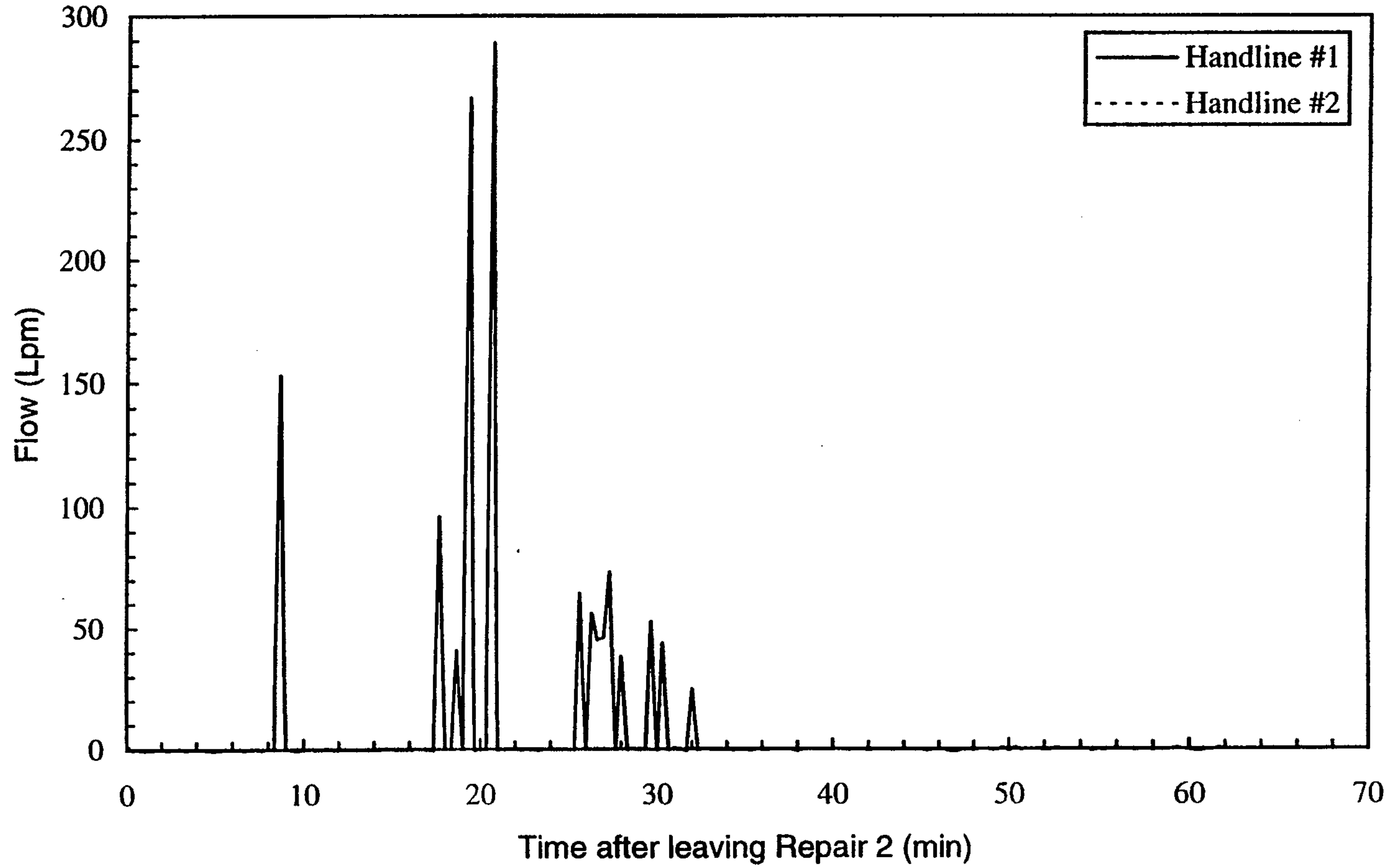

Fig. B22 - Second deck handline flows, Test scba_05

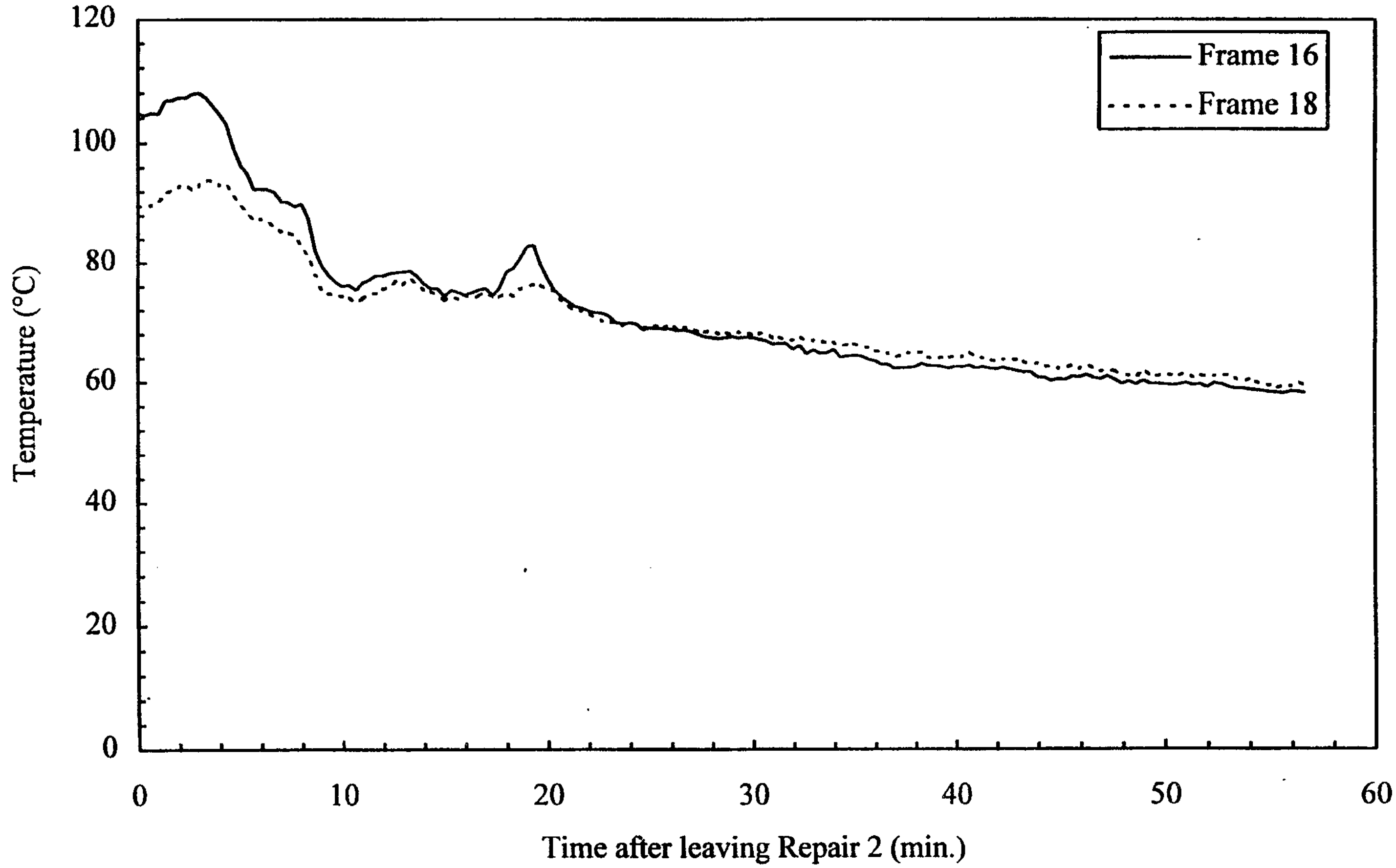

Fig. B23 - Average overhead temperatures in GSK by frame number, Test scba_06

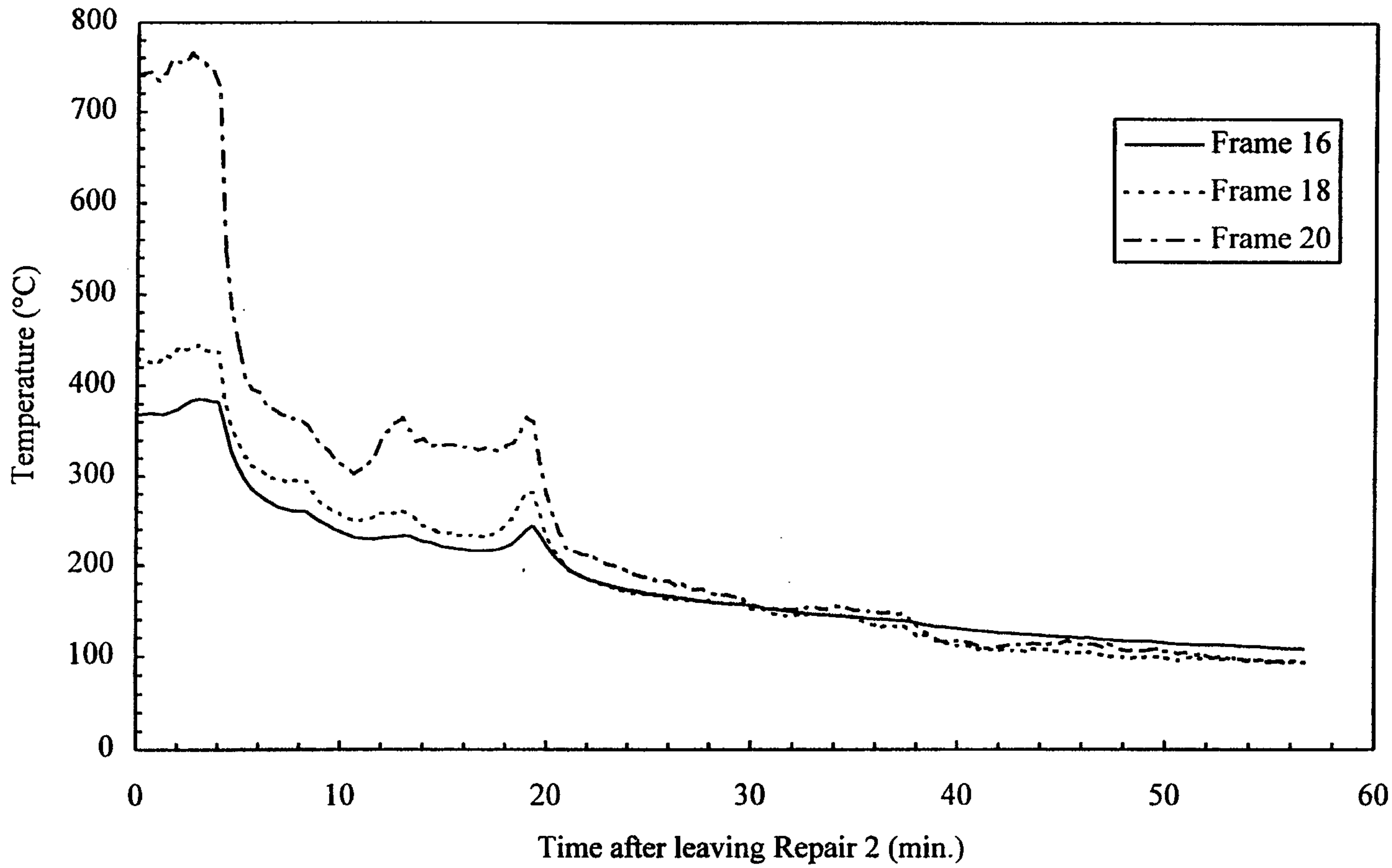

Fig. B24 - Average overhead temperatures in Storage by frame number, Test scba_06

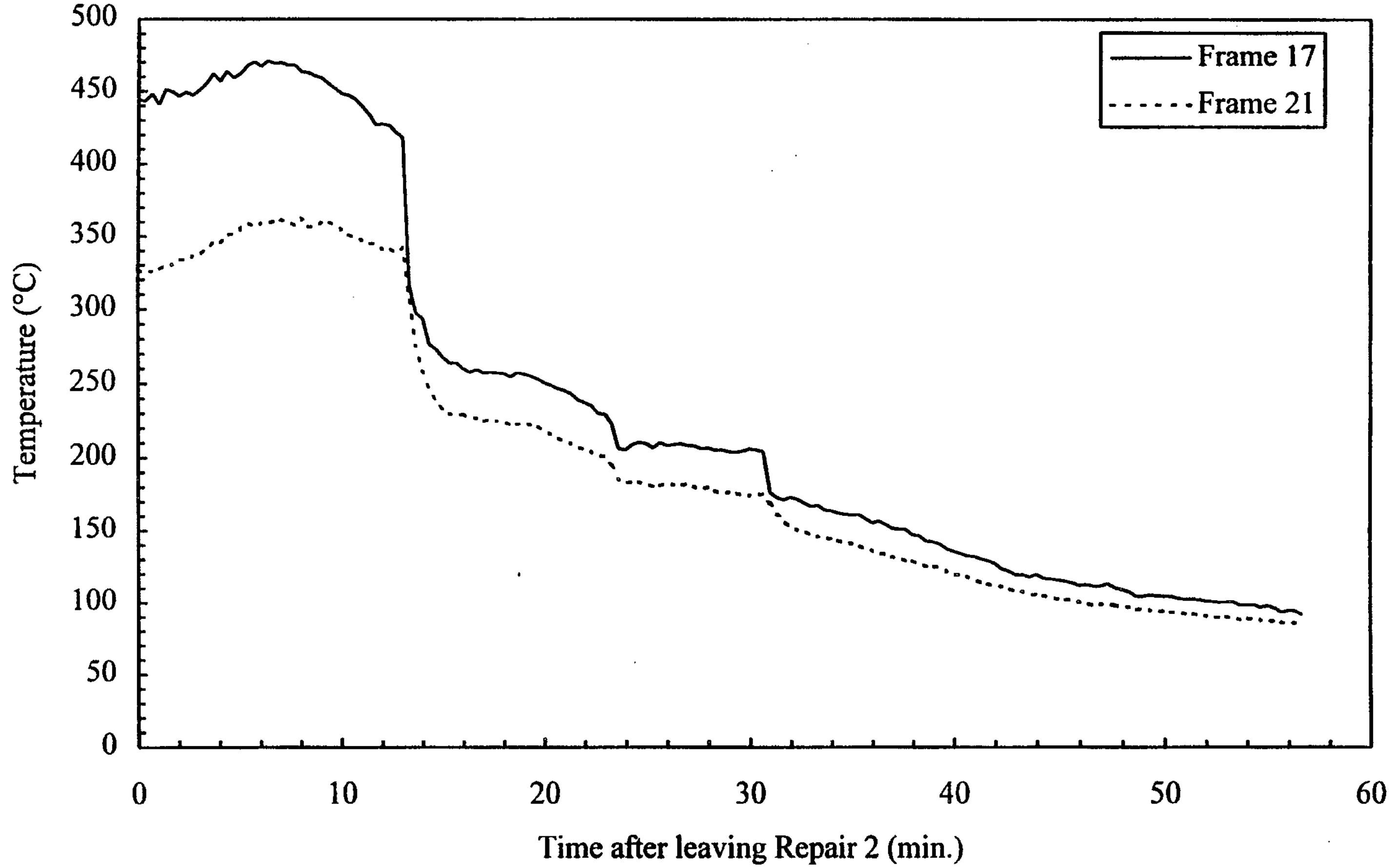

Fig. B25 - Average overhead temperatures in Berthing 2 by frame number, Test scba_06

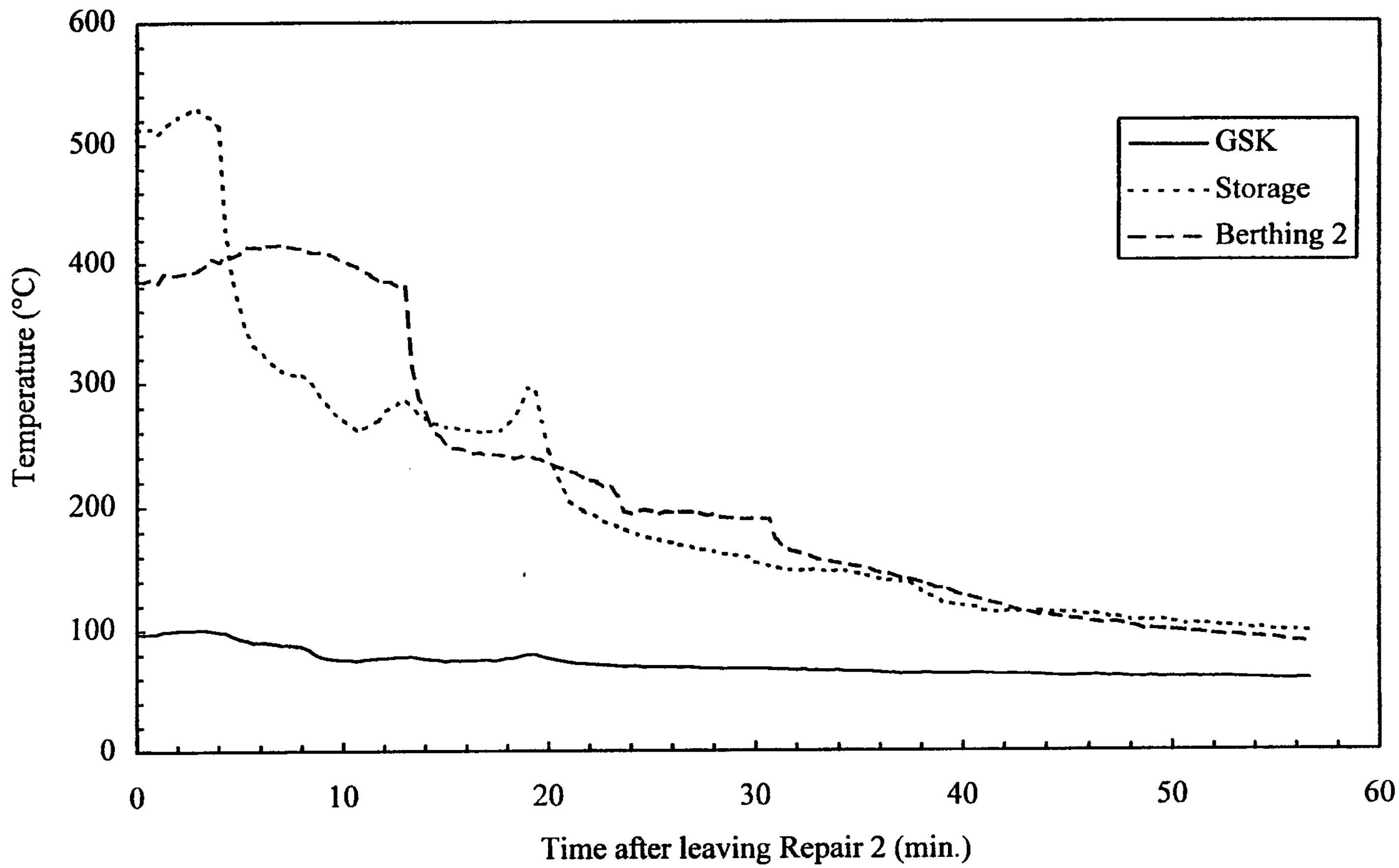

Fig. B26 - Average overhead temperatures in test compartments, Test scba_06

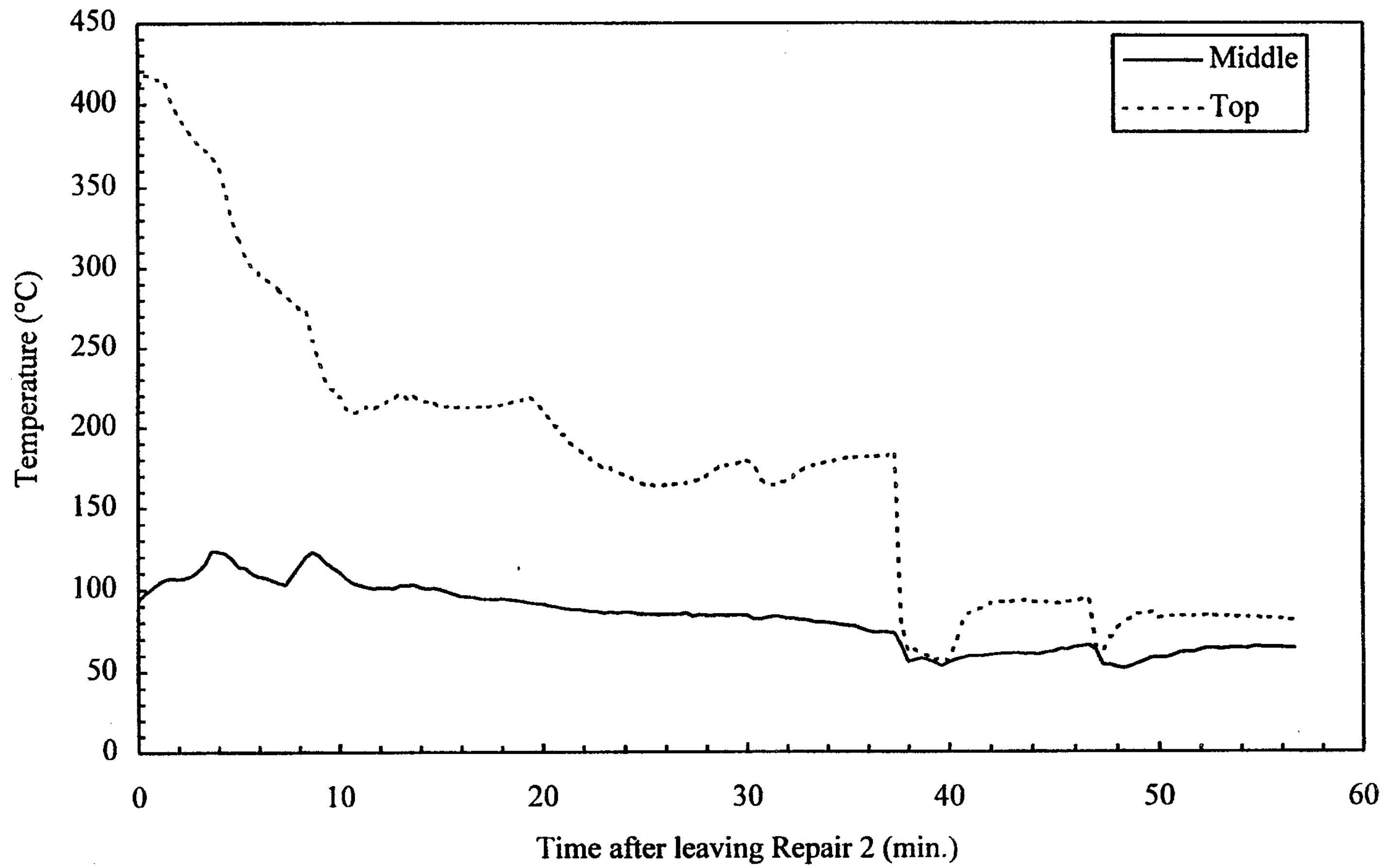

Fig. B27 - Crib 1 temperatures, Test scba_06

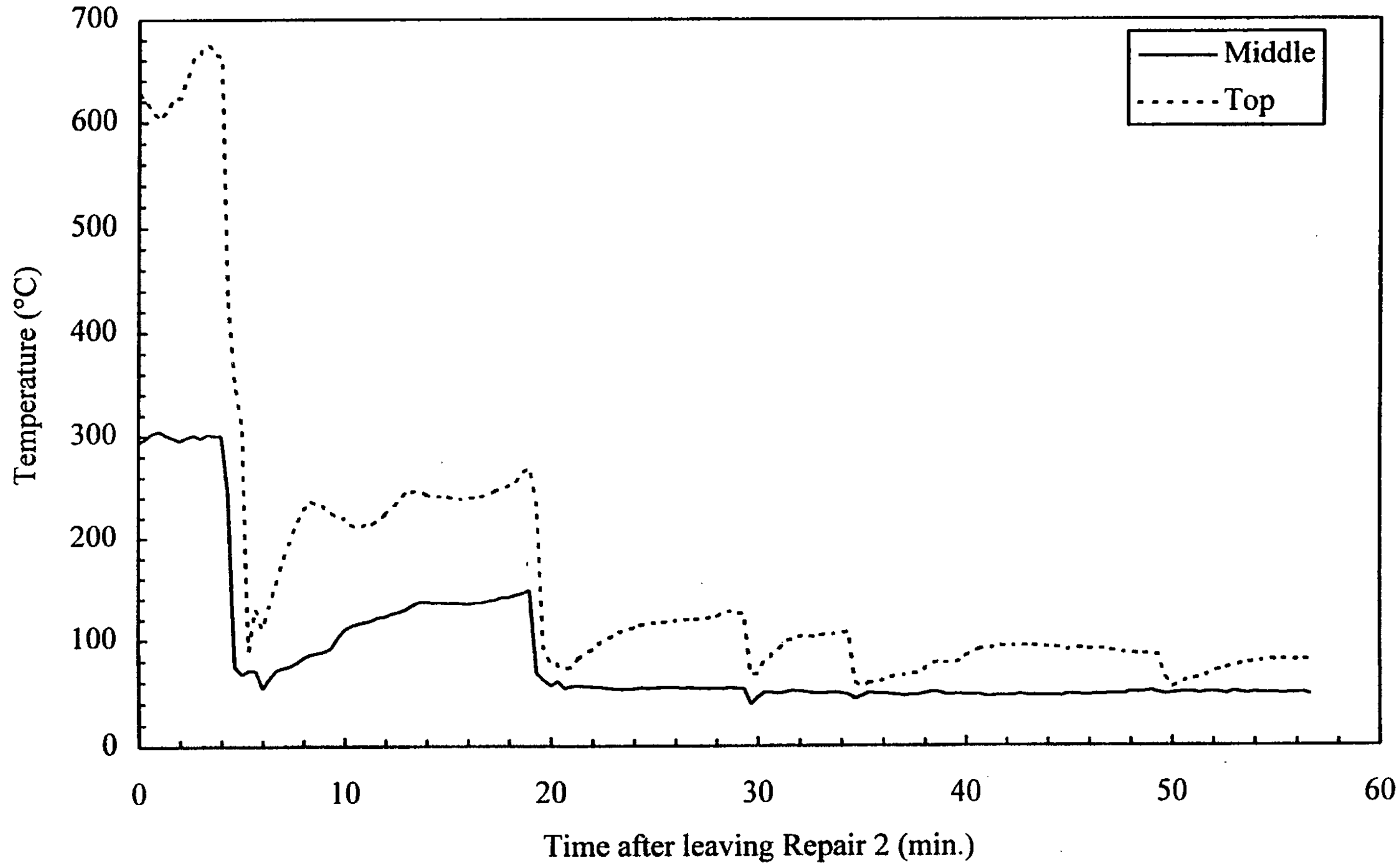

Fig. B28 - Crib 2 temperatures, Test scba_06

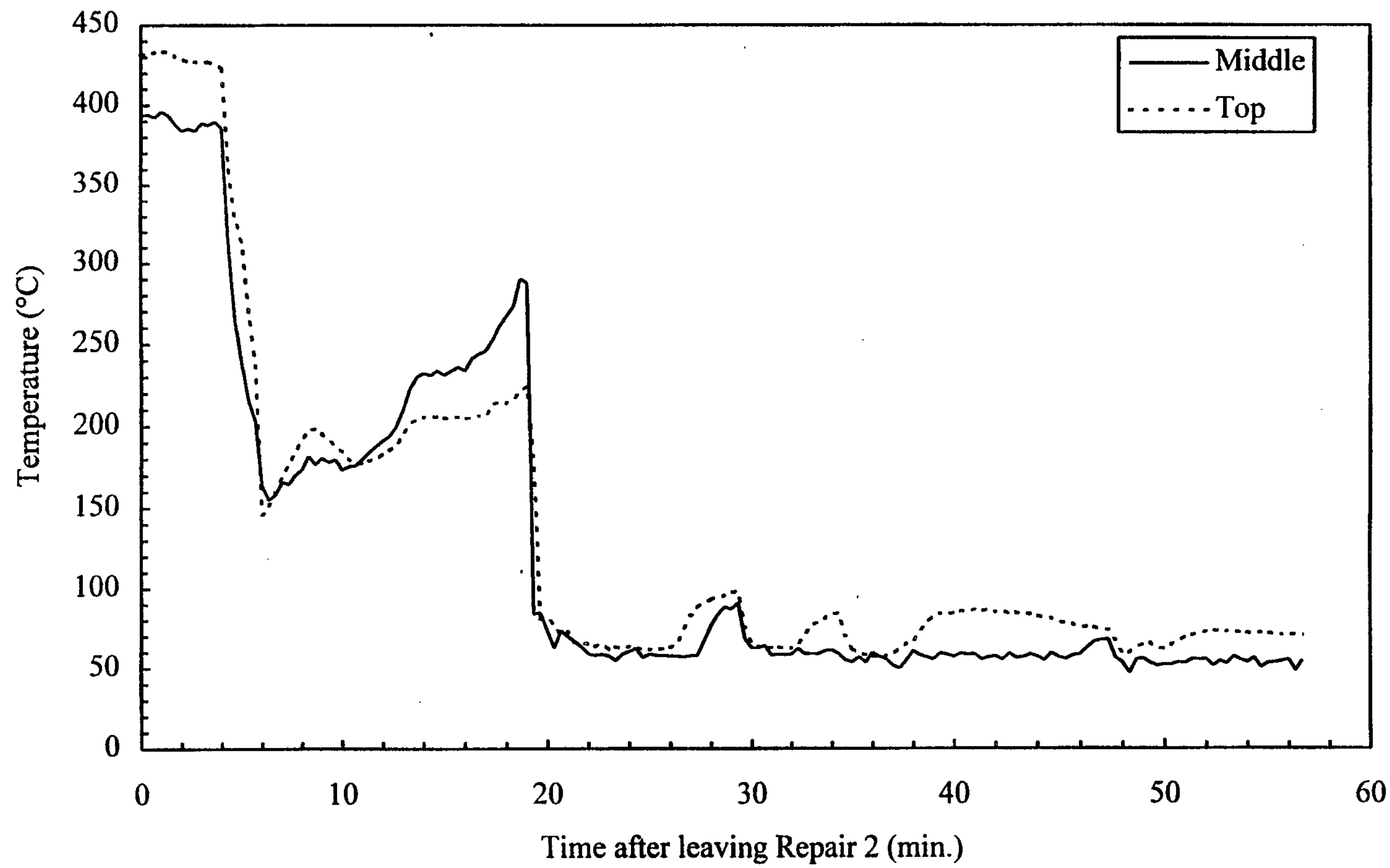

Fig. B29 - Crib 3 temperatures, Test scba_06

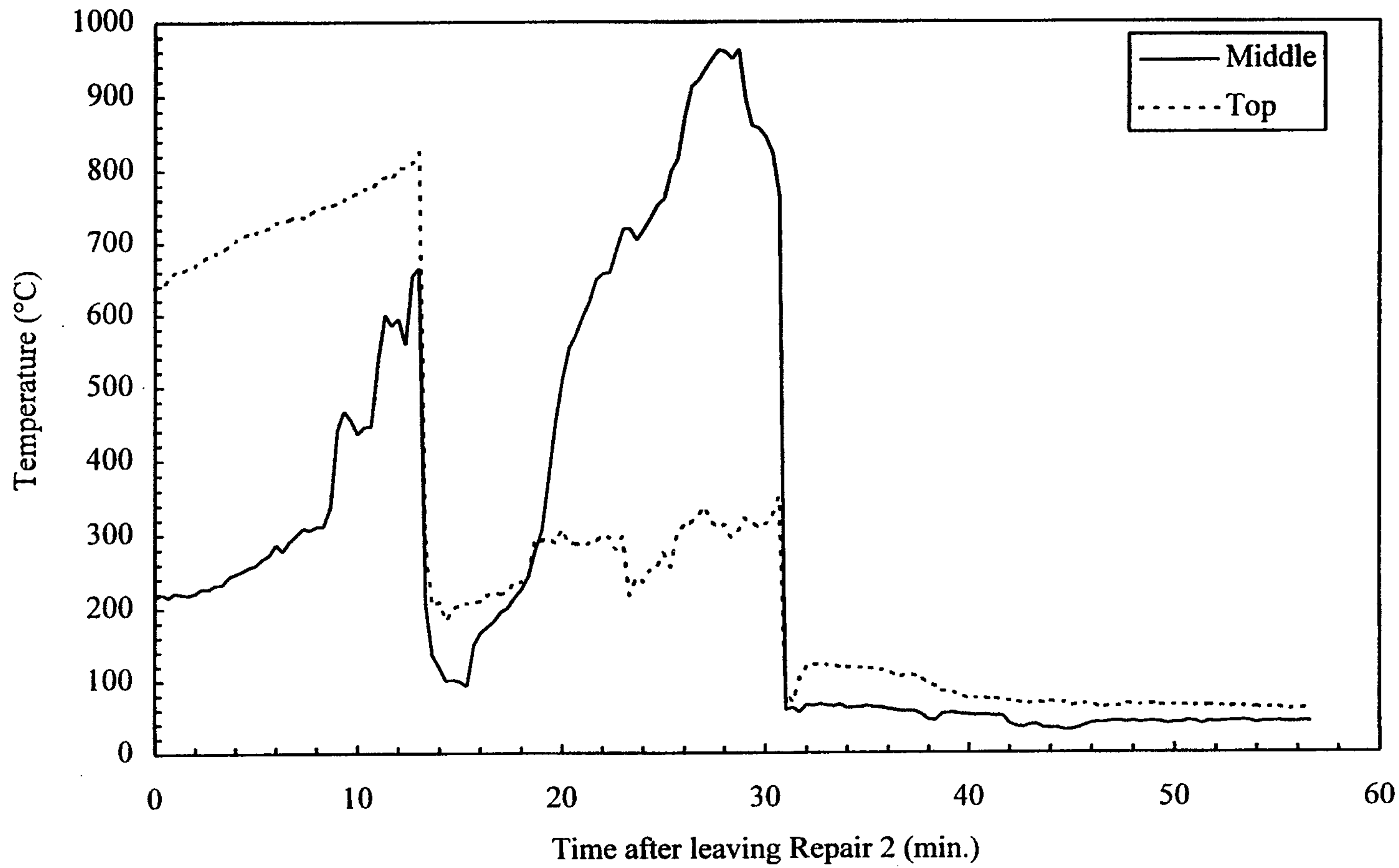

Fig. B30 - Crib 4 temperatures, Test scba_06

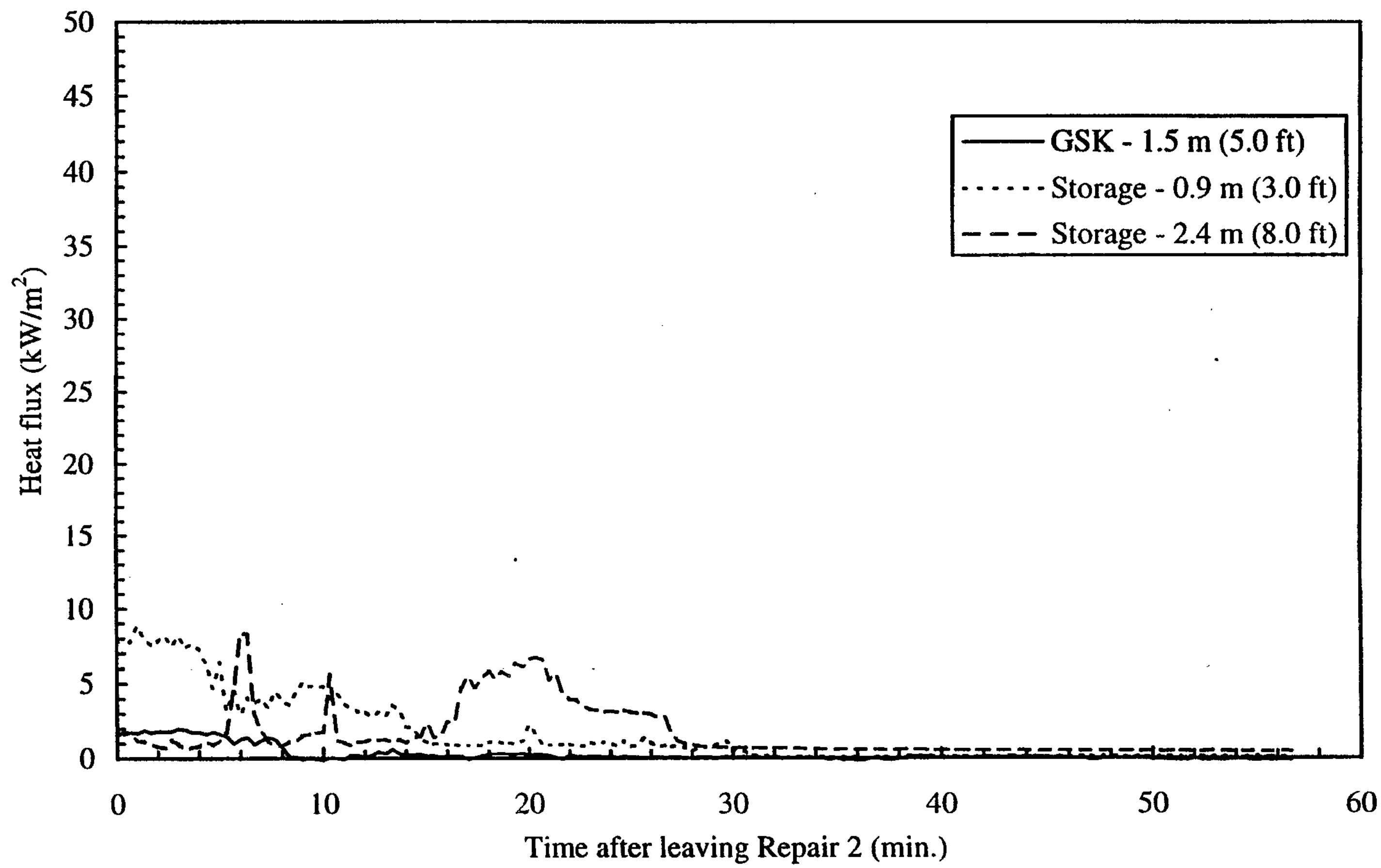

Fig. B31 - Total heat flux in GSK and Storage, Test scba_06

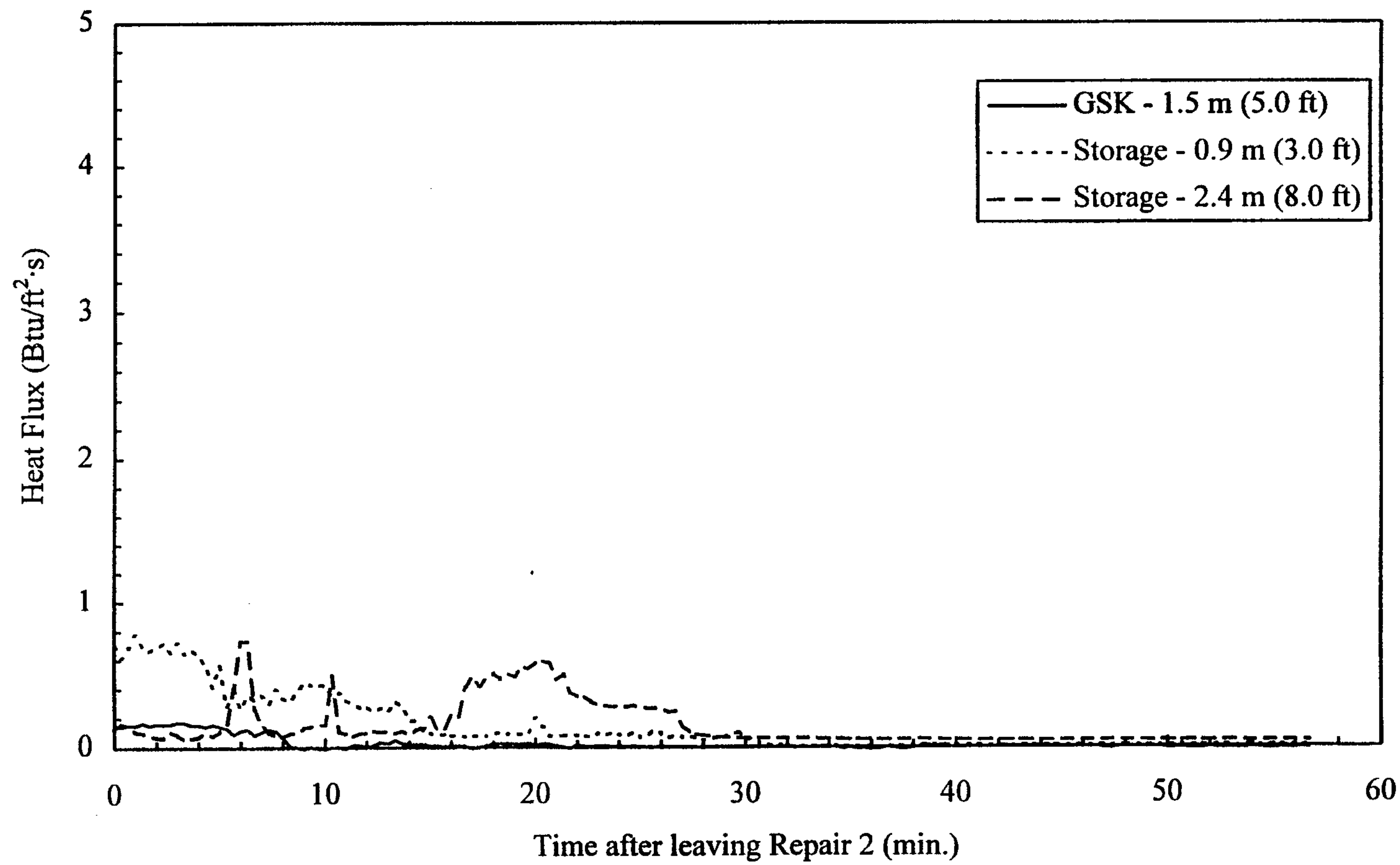

Fig. B31 - Total heat flux in GSK and Storage, Test scba_06

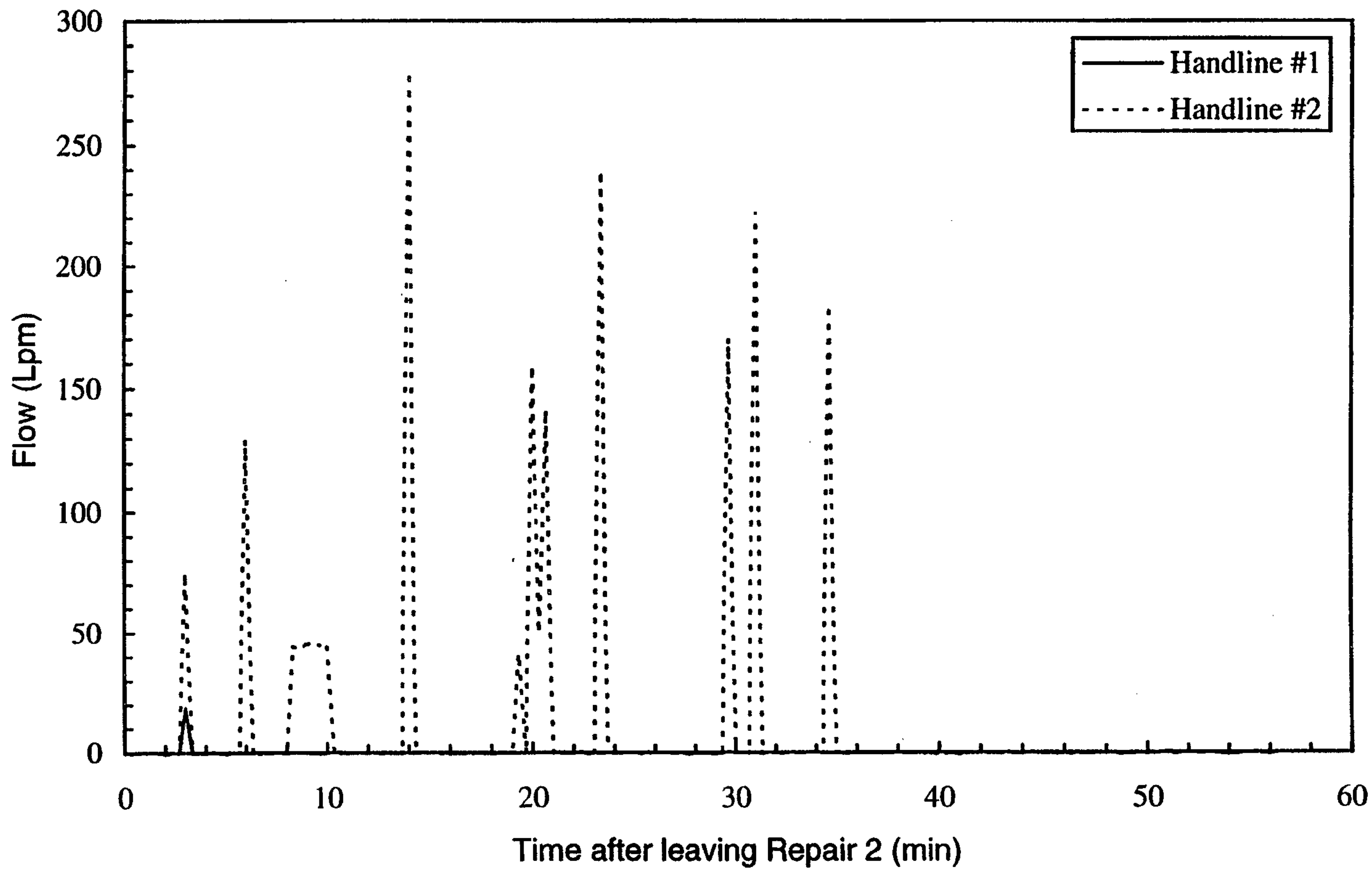

Fig. B32 - Second deck handline flows, Test scba_06

Appendix C

Timelines of Key Events

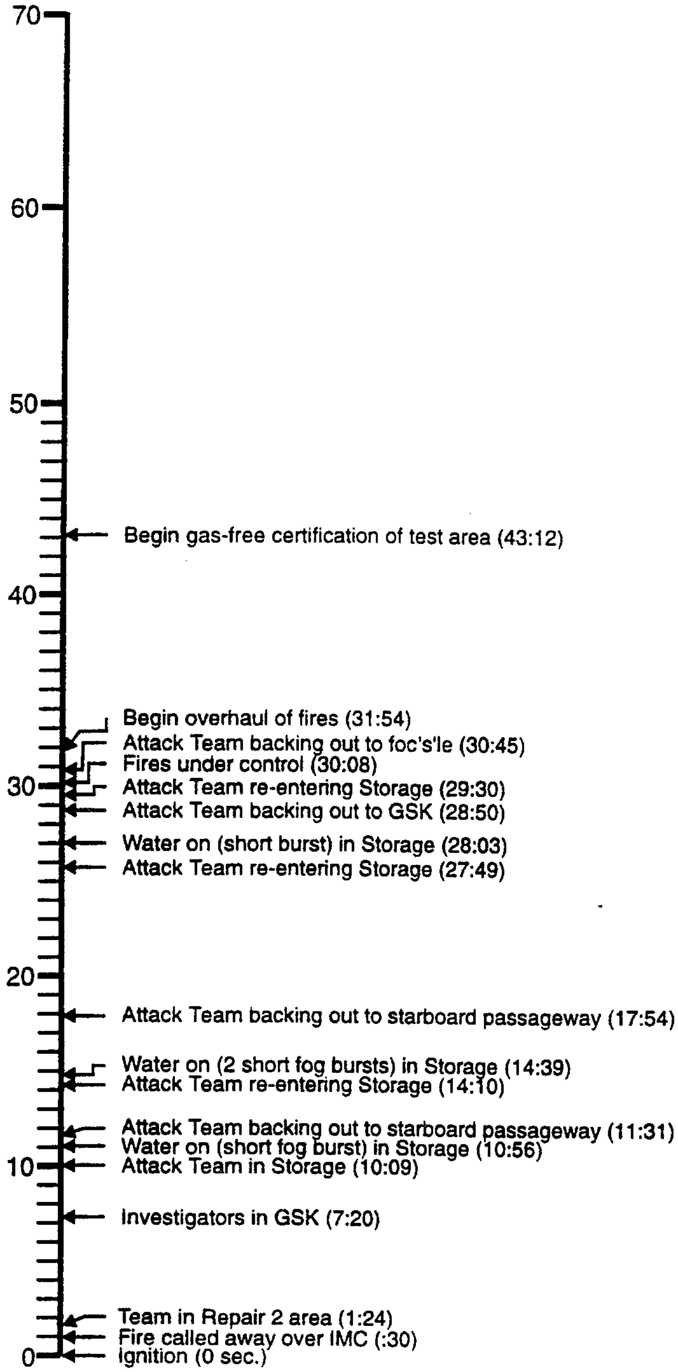

Fig. C1 — Timeline of events for Test SCBA-03

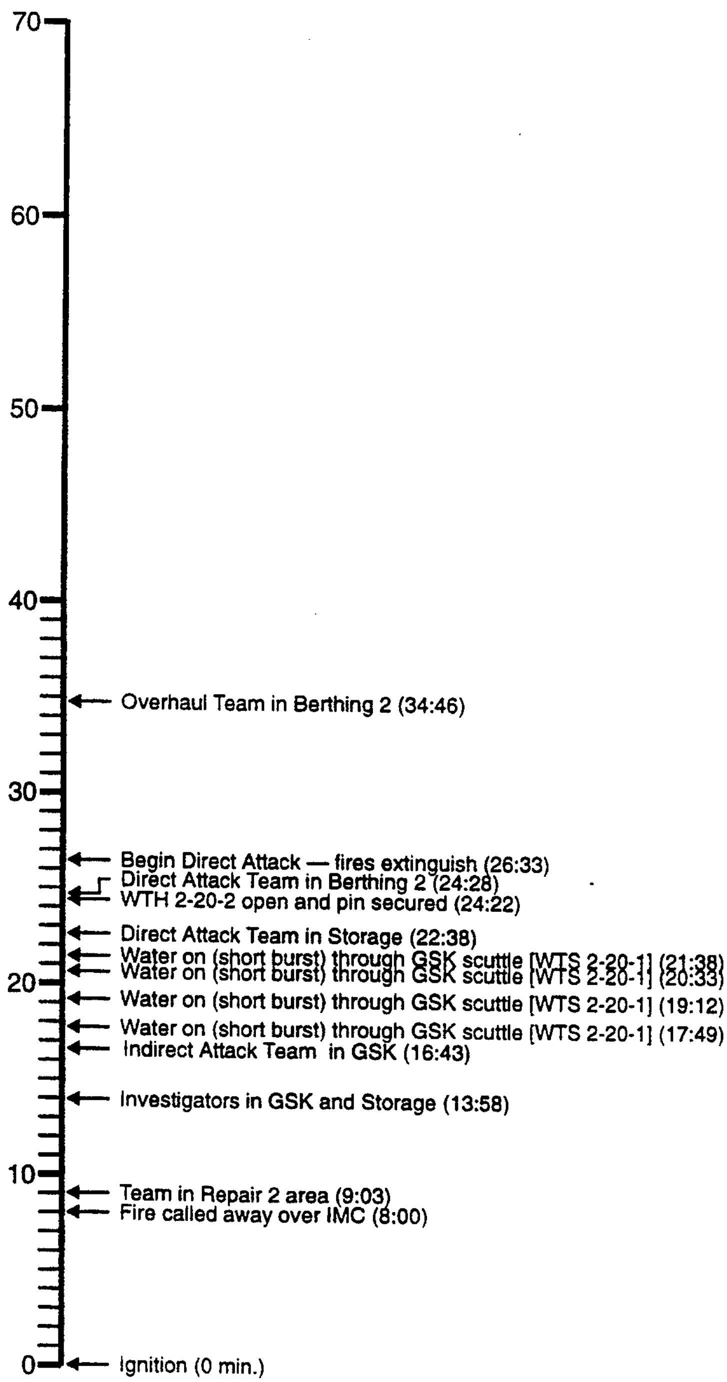

Fig. C2 — Timeline of events for Test SCBA-04

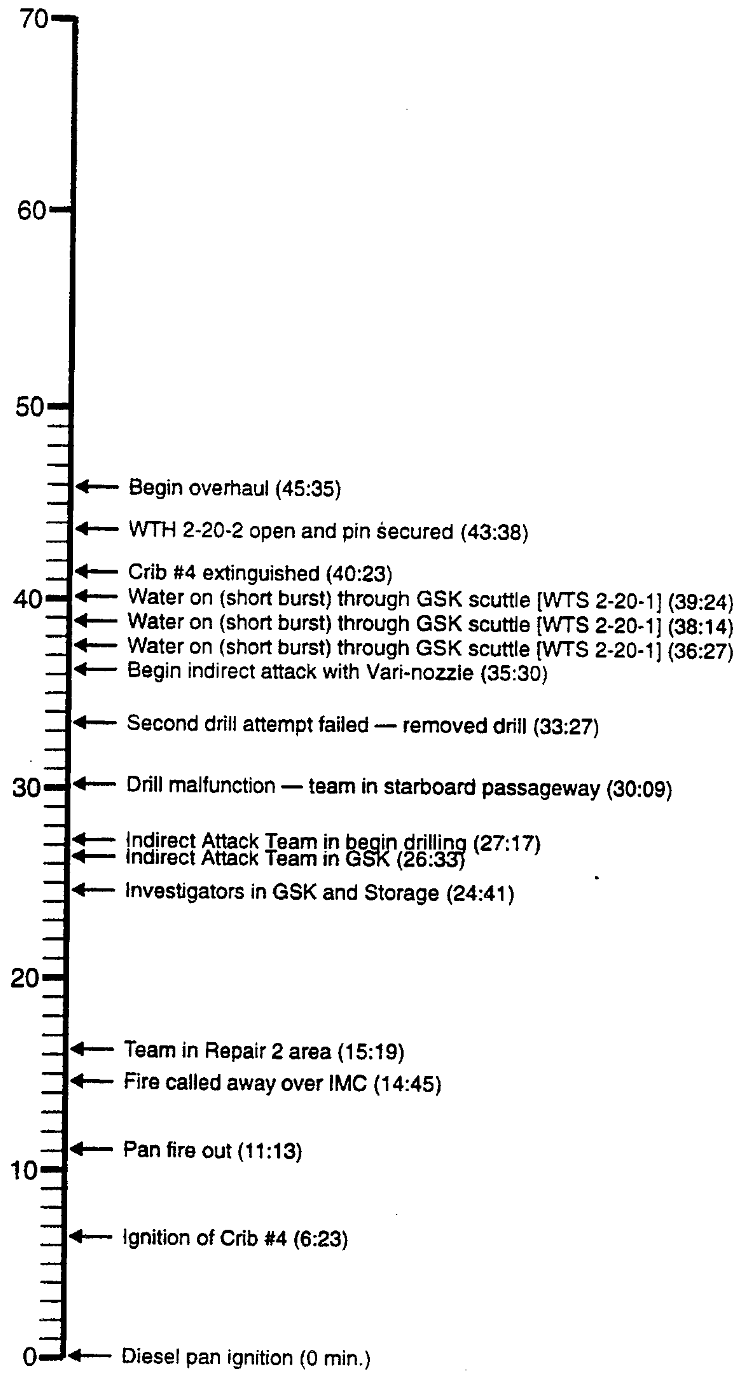

Fig. C3 — Timeline of events for Test SCBA-05

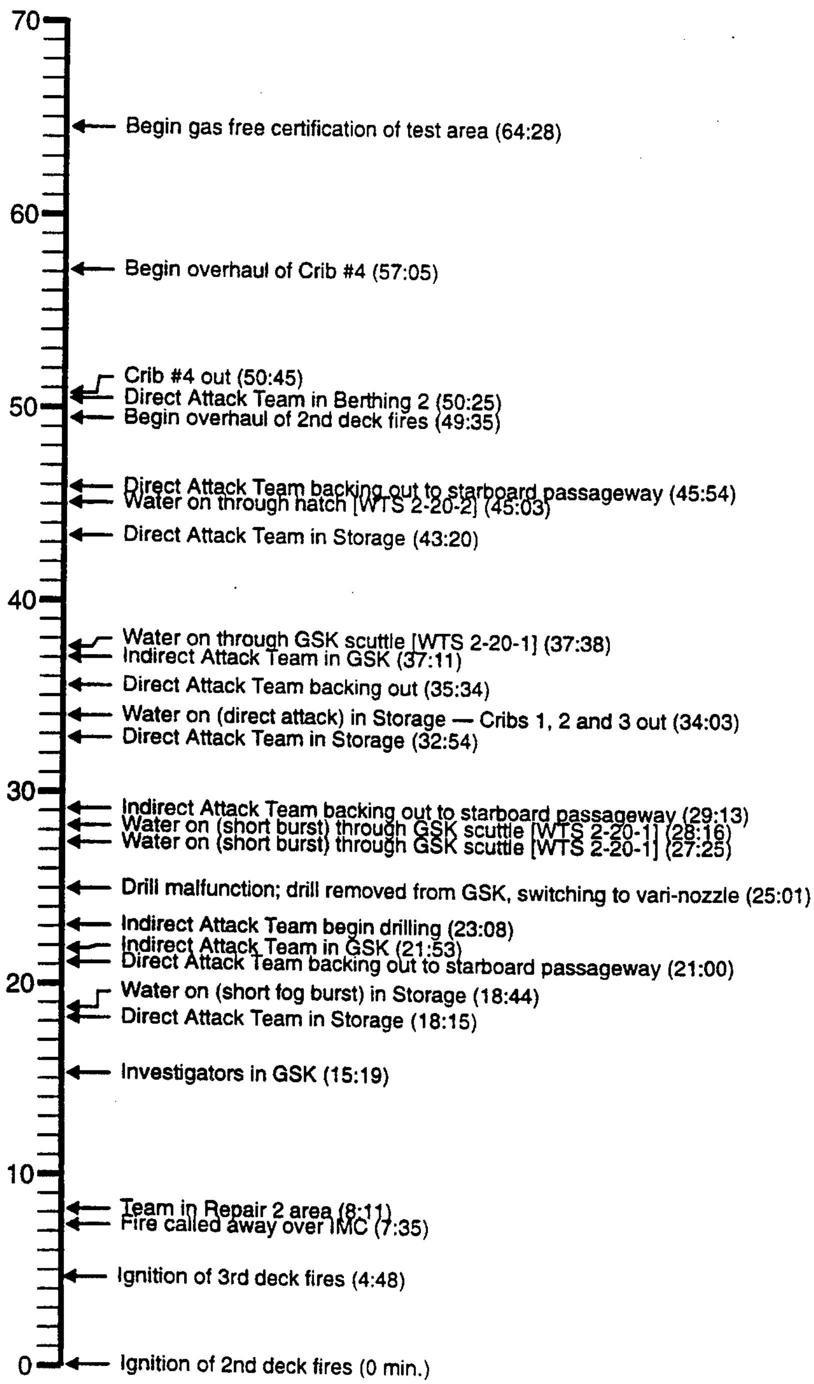

Fig. C4 — Timeline of events for Test SCBA-06